

# **A Gamified Rock Engineering Teaching System**

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Thesis submitted for examination for the degree of Master of  
Science in Technology.

Espoo 04.11.2020

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**Title** A Gamified Rock Engineering Teaching System

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**Degree programme** ICT Innovation

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**Major** Human-Computer Interaction and Design

**Code of major** SCI3020

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**Supervisor** Prof. Perttu Hämäläinen

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**Date** 04.11.2020

**Number of pages** 78+7

**Language** English

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**Abstract**

This thesis addresses the lack of gamification in rock engineering educational applications. The goal of this thesis was to create an enjoyable and effective rock fracture mapping learning experience using virtual reality (VR) and gamification. The hypothesis is that gamification can improve the learning experience and learning outcomes of learners. A concrete output of this thesis is a gamified teaching system GRETS (Gamified Rock Engineering Teaching System). The system includes a teaching module of three concepts related to structural mapping and a gamified practical exercise module. In this thesis, the influence of gamification on the learning experience and learning outcomes was measured through a mixed-method user study. In the user study, a non-gamified rock engineering teaching system (NGRETS) was created as a controlled environment, and the learning experience of both systems was compared to measure the impact of gamification. According to the user study result, GRETS provided learners with an enjoyable learning experience, and their learning outcomes were improved. For instance, the accuracy index, which represents learners' measurement accuracy, was doubled. Although the quantitative data is inconclusive due to various limitations, the thesis advances the gamification of rock engineering education and provides a novel example case that other gamification researchers, designers, and educators can build on.

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**Keywords** Gamification, rock engineering, geology, virtual reality, human computer interaction

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## Preface

It was quite lucky to do a thesis related to my own interest, and I wish to thank Mateusz and Lauri for providing such an opportunity. I had an enjoyable working experience in the Mineral Materials and Mechanics research group. I want to thank our team members Mateusz, Lauri, and Prof. Mikael, for their help and guidance. Special thanks to Mateusz, who is the advisor of this thesis and always be patient and supportive to me, and Prof. Perttu, who provides useful advice and guidance whenever I turned to him. Also, big thanks to participants who were willing to be involved in this experiment.

In addition, I also want to thank my family and friends for their care and support throughout the thesis project.

Otaniemi, 25.10.2020

Xiaoyun Zhang



# Contents

<b>Abstract</b>	<b>3</b>
<b>Preface</b>	<b>4</b>
<b>Contents</b>	<b>5</b>
<b>Symbols and abbreviations</b>	<b>7</b>
<b>1 Introduction</b>	<b>8</b>
1.1 Research Questions . . . . .	10
1.2 Methodology . . . . .	10
1.3 Structure of Thesis . . . . .	11
<b>2 Background</b>	<b>12</b>
2.1 Virtual reality . . . . .	12
2.2 VUTE . . . . .	12
2.3 Gamification . . . . .	13
2.4 Self-determination theory . . . . .	15
<b>3 System design</b>	<b>16</b>
3.1 Pedagogical goals . . . . .	16
3.2 The Platforms . . . . .	17
3.2.1 Virtual reality device selection . . . . .	17
3.2.2 Software development platform . . . . .	19
3.3 Teaching flow . . . . .	19
3.4 Virtual environment design . . . . .	20
3.5 Interaction design . . . . .	21
3.5.1 General interaction design . . . . .	21
3.5.2 Remote measuring design . . . . .	25
<b>4 Gamification design</b>	<b>29</b>
4.1 Game elements . . . . .	29
4.2 GRETS gamification design . . . . .	32
4.3 Physical Badge . . . . .	36
4.4 NGRETS . . . . .	38
<b>5 Evaluation</b>	<b>40</b>

5.1	Target group . . . . .	40
5.2	The first round user study . . . . .	40
5.2.1	Participants . . . . .	40
5.2.2	Methodology . . . . .	41
5.2.3	Result . . . . .	42
5.3	The second round user study . . . . .	46
5.3.1	Participants . . . . .	46
5.3.2	Methodology . . . . .	46
5.3.3	Result . . . . .	47
5.4	Problems of traditional teaching and feedback from educators . . . . .	62
5.4.1	Results . . . . .	63
<b>6</b>	<b>Discussion</b>	<b>65</b>
6.1	Limitations . . . . .	66
6.2	Future work . . . . .	69
<b>7</b>	<b>Conclusion</b>	<b>71</b>
<b>A</b>	<b>Appendix</b>	<b>79</b>
A.1	UPEQ questionnaire . . . . .	79
A.2	Interview questions . . . . .	83
A.2.1	The first round of user study for badge types . . . . .	83
A.2.2	The second round of user study for gamification . . . . .	83
A.3	Demo videos and published website . . . . .	84
A.3.1	Demo videos . . . . .	84
A.3.2	Published website . . . . .	84

# Symbols and abbreviations

## Symbols

I	Accuracy index
$\omega_n$	Difficulty coefficient weight for joint set n
$N_{Identifications_{JS}}$	Identification counts of all joint sets
$N_{Identifications_{JSn}}$	Identification counts of joint set n
$N_{Measurements}$	Measurement counts
$p_n$	Proportion of the joint set's distribution area
R	Correct rate

## Abbreviations

COVE	Conceptual Orienteering in Virtual Education
CS	Computer Science
GAMS	Gaming Motivation Scale
GRETS	Gamified Rock Engineering Teaching System
IT	Informational Technology
Kwall	Karhusaari rock wall measurement exercise
MDA	Mechanics, Dynamics, and Aesthetics
MIEDU	Mining Education and Virtual Underground Rock Laboratory
NGRETS	Non-Gamified Rock Engineering Teaching System
PC	Personal Computer
PENS	Player Experience of Need Satisfaction
SDT	Self-Determination Theory
UPEQ	Ubisoft Perceived Experience Questionnaire
VR	Virtual Reality
VUTE	Virtual Underground Tunnel Environment

# 1 Introduction

It is always a target for school education to seek an attractive way to encourage and support students' learning [1]. Educators are trying to motivate students to learn by themselves and stay for a long period [2], while students are looking forward to a fun, interesting learning experience. Gamification - using game elements in non-game context [3] - is one of the approaches that has been implemented in pursuit of better learning outcomes. The most important reason for adding gamification is that games are believed to be fun, motivational, and engaging for players [4]. There are studies and discussions on the effectiveness of gamification, and it is believed that adding game elements can improve learner's motivation and other learning outcomes than traditional learning content [5][6]. Concretely, game elements can increase learners' intrinsic motivation in three sub-scale (Autonomy, Competence, and Relatedness) according to Self-Determination Theory (SDT), the psychological theory of intrinsic motivation [5][7][8].

This thesis builds on preceding research VUTE (Virtual Underground Tunnel Environment [9]) of this thesis was conducted in 2018 from the rock engineering education perspective, as shown in Figure 1. The goal of VUTE is to verify the possibility of applying VR in rock education and compare it with the traditional exercise method of accessing real tunnels. As a follow-up project, this thesis aims to solve the problems identified in VUTE and improve the experience to strengthen the learning results. This thesis is also a part of the Aalto online learning project called Conceptual Orienteering in Virtual Education (COVE). The goal of COVE is to add additional educational content and improve the teaching potential of the training system developed in VUTE. The thesis aims to build a new system based on VUTE with a simple interaction, instant feedback, better user experience, and learning outcomes.

In this thesis, the primary focus is improving user experience and learning outcomes of rock structural mapping education. The hypothesis is that learners' learning experience and learning outcomes can be improved by applying gamification methods. Although there are several examples of gamified applications, content is lacking in rock engineering, mining, and geology education. In detail, most gamification cases are related to Computer Science (CS) and Informational Technology (IT) [1]. Hence, there is a need for a gamified educational case in engineering, specifically in rock engineering. Another fact is that the reward design of all gamification applications is considerably similar. The design of rewards is within seven catalogs: points, badges, levels, leader boards, virtual goods, and avatars [1]. The seven types of



Figure 1: VUTE [10][11]

rewards are commonly used and widely adopted, but they might not be the most appropriate rewards for the selected teaching content. In other words, besides the above seven types, there might be other reward types more appropriate for the gamified educational content. The proposal is that a context-related reward design could highlight the advantages of learning platforms, thus enhancing users' learning experience. To find out, this thesis attempts to design and develop a unique badge in VR - "the physical badge" and compare its performance with traditional badges. More detail about the physical badge is discussed in later chapters.

A concrete output of this thesis is the Gamified Rock Engineering Teaching System (GRETS), designed and developed for teaching rock structural mapping with an interactive gamified system. GRETS consists of a concept teaching module and a practical exercise module. The teaching module includes teaching materials about three rock structural mapping concepts - dip, dip direction, and joint set (the concepts are introduced in chapter 3.1). The exercise module is a virtual practice of all concepts in a simulated situation, where users need to measure the dip and dip direction on a photorealistic rock wall and find all joint sets of the rock wall. In detail, dip and dip direction as the characteristics of a rock mass, require learners to measure the rock mass. Moreover, learners are expected to identify the joints on the rock wall model based on the understanding of their measurements. For the purpose of evaluating the GRETS system, user studies were conducted to identify the better badge type and compare the learning experience and outcomes between gamified and non-gamified conditions.

## 1.1 Research Questions

This thesis aims to create an enjoyable and effective learning experience using the gamification method in rock characterization and structural mapping. In order to measure the impact of gamification methods, two interactive systems were designed and developed - the Non-Gamified Rock Engineering Teaching System (NGRETS) and GRETS, along with a within-subject user study. Both learning experience and learning outcomes were measured in the user study, including intrinsic motivation as one aspect of learning outcomes. Ubisoft Perceived Experience Questionnaire (UPEQ) [8] was used to collect quantitative data towards intrinsic motivation.

The primary research question is: Could gamification improve the learning experience and learning outcomes? To answer this research question, the following five sub-questions need to be answered to measure the learning experience and outcomes.

- RQ1: Is GRETS gamified?
- RQ2: Does gamified content help users to learn?
- RQ3: Do users enjoy the learning experience?
- RQ4: Does gamified content have an impact on learning outcomes?
- RQ5: Which game element improves the learning experience the most?

## 1.2 Methodology

For the purpose of evaluating gamified content effectiveness, a mixed-methods user study was conducted to evaluate user experience and measure users' learning outcomes. Concretely, the two interactive teaching systems designed and developed in this thesis have the same teaching content but different exercise modules. The exercise module of GRETS is gamified, while the exercise module of NGRETS is not gamified. In order words, the user study was designed into a comparative experiment in which the only manipulated variable is the existence of gamified content.

In this comparative experiment, 14 participants (12 master students, 1 bachelor student, and 1 Ph.D. candidate) from the Aalto University were involved in the experiment, and every user test lasts for around 90 - 120 minutes. They were divided into two groups. The first group of 4 users tested the gamified applications of two badge designs (traditional badges and physical badges) to obtain a better reward design. They were asked to test with two systems, answer the UPEQ questionnaires,

and answer a few questions based on their behaviors. According to these results, GRETS was improved to have a better user experience, such as explicit instruction and suitable badge type. The second group of 10 users tested NGRETS and GRETS applications to get the influence of gamification. In each user test, users played two systems in random order to reduce the bias caused by the test sequence.

The data collected in the experiment was divided into quantitative and qualitative. The quantitative data was mainly used to record the user's behavior in the system, including system identity, the learning period of each concept, the user's measurements in practice, and two UPEQ questionnaire item answers. The qualitative data came from some reactions in user tests and answers to interview questions, including the user's learning outcome, feelings about the learning experience, the difference between the two systems, and learning motivations.

### **1.3 Structure of Thesis**

The thesis includes the following chapters:

1. Introduction - overview of the thesis, the goal and hypothesis, and methodology.
2. Background - literature reviews of the thesis, including virtual reality, gamification, and self-determination theory.
3. Systems design - design and development details of virtual environment, teaching content and interaction design.
4. Gamification design - design and development details of GRETS and NGRETS.
5. Evaluation - user design and results.
6. Discussion - discussions, limitations, and future work.
7. Conclusions - conclusions of the thesis.

## 2 Background

### 2.1 Virtual reality

Virtual reality (VR) is one of the well-known concepts, referring to a real or simulated environment in which a perceiver experiences telepresence [12]. VR itself is not a new technology, and in fact, the earliest recorded VR application was a simulation training program of the US Air Force in 1966 [13]. Even in the field of education and training, there are VR applications from 1980's [14]. However, since 2016 (known as the first year of VR), the VR technology market has expanded, and the total investment in the VR field has also increased [15]. Most people started to heard about VR and learned about VR-related applications. Besides, with the popularization of VR hardware devices such as HTC VIVE and Oculus Rift, VR has been more widely used in various fields, such as medicine (simulated surgery [16]), transportation (simulated driving [17]), military (soldier training [18]), entertainment (beat saber <sup>1</sup>). In education, many studies have attempted to apply VR in various subjects to help students have a more immersive, attractive learning experience with better learning results [19]. The VR application examples include human-patient simulators for surgical teaching in medical education [20], visual simulation of bridge construction in architecture [21], ski jumping training simulator in sports education [22] and a virtual plant environment of a milk powder process in chemical engineering education [23].

### 2.2 VUTE

The preceding research applied VR technology to structural mapping and rock mass characterization from the rock engineering education perspective [10]. It belongs to a part of Aalto online learning pilot project called Mining Education and Virtual Underground Rock Laboratory (MIEDU) [24] and the first interactive system demo was created in 2018 in Virtual Underground learning Environment (VUTE) [9]. Concretely, a photorealistic digital twin of the actual tunnel in the Underground Research Laboratory of Aalto University was implemented using Virtual reality (VR) for teaching purposes. VUTE focused on adding VR technology in rock engineering education to help students learn and practice without visiting the actual tunnel, and a user study was conducted to evaluate the usability of the system and learning outcomes. The result of VUTE indicated that by implementing VR in rock

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<sup>1</sup><https://beatsaber.com/>



engineering, students' learning experience was enhanced. VUTE has good usability, and the usage of Virtual tunnel visits is cheaper, safer, and faster than real tunnel visit [10] with more active learning attempts (measurements) from students [9]. However, there were several issues discovered during the same user study. The most frequent problem mentioned was that users complained about the measuring module, which used the digital replica of real-life tools. Many users also mentioned replacing the measuring tool with simple action, like a button click, which is much more convenient and user friendly. Besides, many users complained about the date input tool for recording measurements too complicated. Users did not get instant feedback about their measurements because the data was handled after the experiments. Hence, the user experience of the VUTE system needs to be improved despite good usability.

This thesis is based on the current findings and focus on the interaction design and the improvement of user experience by importing three following concepts.

## 2.3 Gamification

Gamification is a method that uses game elements for non-game context to improve user experience [3] and enticing users to perform expected behaviors [25]. The concept of gamification was separated from the concept of game design and product design. In game design, the old gamification is called "game with a purpose" (GWAP), which refers to the unplanned completion of a human task while playing a game [26]. For example, when a player is playing a somatic trampoline game, in order to win points, he or she needs to jump high on the trampoline. While the player wins the score, he or she also carries out the task of jumping, which is physical exercise [27]. However, this somatic trampoline game is still a game rather than a gamification application because the task (physical exercise) is just a side effect of playing the game. On the other hand, in other design fields such as product design, the early concept of gamification is close to ludic design or ludic activities [3], which refers to "activities motivated by curiosity, exploration and reflection rather than externally defined tasks" [28]. Users can have a motivated, engaged, and playful experience with ludic design while interacting with the artwork [29].

In a way, the concept of gamification is like a combination of these two origins, as a purposeful game or a playful product. These are also two characteristics of gamified products, one is goals, and the other is playfulness. Thus, the output system of this thesis was designed and developed from these two aspects.

As mentioned earlier, the difference between games and gamification applications is the application of game design in non-game scenarios. Nevertheless, this does not just represent that moving game elements to applications in other fields or copying the game to a new scene and imposing a goal to a game is a gamification application [30]. More specifically, a gamification application needs first to identify its goal - what kind of behavior to encourage. Then design appropriate content and game mechanics to achieve its goal [31].

Similarly, the setting of rewards for certain behaviors often appears in traditional teaching [30], which is also an important application direction of gamification. There have been many studies on gamification applications and pointed out that gamification plays an important role in motivation and engagement [1]. There are a few research cases and business cases about applying the gamification method by importing game elements and mechanics on education to engage students and correct their behaviors. For instance, a mobile game-based learning system eMgage for university education was designed in 2014 by Bartel [32], a teaching case was conducted with the field of architectural engineering in 2014 by Villagrasa [33], and successful business platforms of ClassCraft <sup>2</sup>, Rezzly <sup>3</sup> and Seppo <sup>4</sup> [34].

Gamification is divided into two types, one is reward-based, and the other is meaningful, corresponding to improving extrinsic motivation and intrinsic motivation [34]. Extrinsic motivation and intrinsic motivation are both motivation types, where extrinsic motivation refers to doing something to gain external rewards. On the contrary, intrinsic motivation refers to doing something for the sake of it [35]. In other words, reward-based gamification uses external rewards such as points, levels, or badges to motivate users to achieve the goal while meaningful gamification attempts to stimulate users' interests towards the goal and persuade users to take the initiative to complete the goal. For example, the way we train children to use the toilet or dogs to sit always uses some "reward," such as snacks, encouraging words, or even punishment, and children or dogs do what we expect to get or avoid external "rewards." However, it is almost impossible to use the same kind of "reward" to train a student to like mathematics because it is intrinsic and requires long-term effort. Thus, when expecting immediate and short-term influence like skill training, the reward-based gamification is effective [36]. However, the encouraging behavior might stop once the reward stopped [36] in reward-based gamification, and this does not

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<sup>2</sup><https://www.classcraft.com/>

<sup>3</sup><https://www.rezzly.com/>

<sup>4</sup><https://seppo.io/>

suit teaching objectives in education. Hence, we are trying to trigger the intrinsic motivation of learners as well as their enjoyment of the learning experience.

## 2.4 Self-determination theory

Self-determination theory (SDT) is a macro psychological theory of human motivation and personality relevant to personal growth, psychological needs, self-regulation, and other aspects of personal well-being [7][37][38]. In detail, SDT focuses on how people make decisions and behave based on their self-motivation and personality integration without external influences or interference [39][37]. On the other hand, one individual's intrinsic motivation also affects individual choices and behaviors, which is consisted of SDT. Intrinsic motivation is one perspective of SDT, and SDT has been applied to many social psychology fields and education and gamification [40]. In education, SDT indicates that it is students' nature to learn because of curiosity towards their environment [41], and it has been tested in physical education to evaluate a supportive learning environment for secondary school students in the UK [42]. In gamification, SDT is related to UX and player experience. By implementing SDT, many frameworks such as Player Experience of Need Satisfaction (PENS) [43], The Gaming Motivation Scale (GAMS) [44] and Ubisoft Perceived Experience Questionnaire (UPEQ) [8] are developed from SDT to guide player experience evaluations [38].

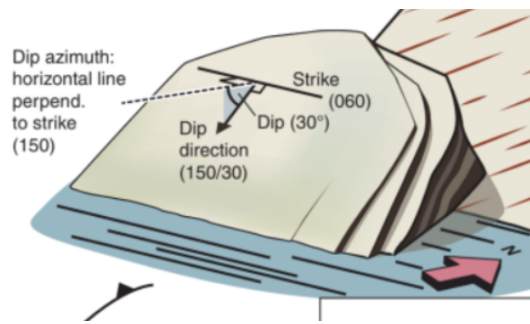
According to SDT, three needs are connected with intrinsic motivation: Autonomy, Competence, and Relatedness [34]. Autonomy is that users have the freedom to choose their own path and feel they are in control [36]. Competence is that users feel they are capable and good at solving given challenges [8]. And Relatedness is that users do not feel alone but inside a community with other users [36]. There are a few studies that found out these three psychological needs also happens in play experiences, and it is related to players' engagement, thus intrinsic motivation [38]. As mentioned above, many frameworks were developed and tested to measure player experience and intrinsic motivation based on SDT. In this thesis, UPEQ is used to evaluate intrinsic motivation, assuming that this relates with the learning outcomes of the developed gamification application GRETS.

### 3 System design

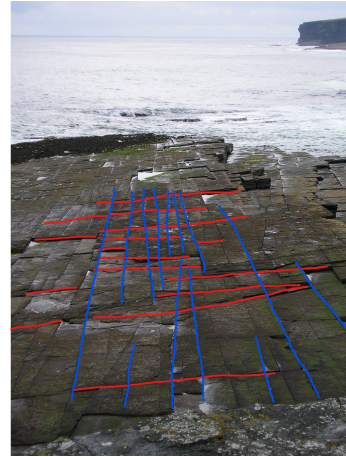
This chapter discusses the design steps of the The Non-Gamified Rock Engineering Teaching System (NGRETS) and Gamified Rock Engineering Teaching System (GRETS): hardware selection, virtual environment design, interaction design. Including hardware description, system development platform, interaction design, and teaching content design. Among them, the remote measurement method design in the interaction design, as one of the inventions of this thesis, is discussed.

#### 3.1 Pedagogical goals

The primary teaching content of GRETS includes three concepts (dip, dip direction, and joint set) in rock characterization and structural mapping. Concretely, the dip angle describes a plane's inclination, and the dip direction is the dip azimuth, which describes the horizontal direction of the plane's dipping [45]. These two concepts are used to describe the orientation of a planar geological structure, such as rock joint [45]. A joint is basically a fracture in a rock mass without displacement, and a joint set is a group of parallel joints in a given space [46][47]. Figure 2 (a) shows the illustration of concepts dip and dip direction, while Figure 2 (b) shows the horizontal joints on a rock wall.



(a) Dip and dip direction [45]



(b) Joint and joint sets<sup>6</sup> (modified by Mateusz Janiszewski)

Figure 2: Teaching concepts in GRETS

In the exercise, users are expected to identify joint sets according to dip and dip direction measurement results from the remote measuring method (details in chapter

<sup>6</sup>[https://commons.wikimedia.org/wiki/File:Joints\\_Caithness.JPG](https://commons.wikimedia.org/wiki/File:Joints_Caithness.JPG)

3.5.2). Concretely, users need to identify the joints on the rock wall model based on the understanding of their measurements. They are required to use dip and dip direction measurement results and their observation on the identified joint according to the joint set definition. In the exercise module, GRETS provides feedback on joint sets based on the dip and dip direction values measured by users. By collecting users' measurement results, their understanding of concepts and practical learning outcome could be analyzed.

## **3.2 The Platforms**

### **3.2.1 Virtual reality device selection**

With the development of hardware, VR technology and equipment began to appear mature enough commercial VR helmets after 2015 to promote VR technology. The first objective of this thesis is to select the appropriate hardware. The devices discussed in this thesis are currently widely used and well-known by users, one is a wired device (tethered VR), and the other is a standalone device. Additionally, display headsets similar to google cardboard are excluded because there is no way to interact with VR content while using the devices.

Tethered VR, such as HTC Vive, Oculus Rift, PlayStation VR, need to be physically connected to an additional device, such as a PC (Personal Computer) or game console. In other words, these devices cost extra money for support equipment, and users' activities are limited by the length of the connection cable. Considering that a possible application scenario of GRETS is an academic teaching context, such as a lecture room, the tethered VR equipment requires the same number of powerful performance PCs. Simultaneously, the maintenance and management of support devices and multiple cables require extra money, time, and human resources. In contrast, the Standalone device itself contains all necessary components and can be used independently without the assistance of external devices. In the same teaching context, standalone reduces the need for accessories and reduces the cost of external device configuration, maintenance, and management.

Furthermore, regarding teaching scenarios, the selection criteria include the performance and price of the devices. In terms of its performance, the primary consideration in this paper is the resolution. GRETS uses photorealistic 3D rock models to get the same measurement results in the virtual environment as in the real environment. The resolution allows users to view the details on the rock models with the same detail

as in the real environment instead of pixelated images. Choosing a less expensive device saves on equipment purchase and maintenance costs. The performance and price results comparing the mainstream tethered devices mentioned in the previous paragraph with the more popular standalone devices are shown in Table 1.

Name	Category	Display	Price(USD)
HTC Vive <sup>1</sup>	Tethered VR	1080*1200	399
Oculus Rift <sup>2</sup>	Tethered VR	1080*1200	Discontinued
PlayStation VR <sup>3</sup>	Tethered VR	960*1080	299
Varjo VR-1 <sup>4</sup>	Tethered VR	1920*1080	5995
Oculus Quest <sup>5</sup>	Standalone	1440*1600	399
Oculus Go <sup>6</sup>	Standalone	1280*1440	199
Google Daydream View <sup>7</sup>	Standalone	Mobile Screen	Discontinued
Samsung Gear VR <sup>8</sup>	Standalone	1280*1440	99
Pico G2 4K <sup>9</sup>	Standalone	1920*2160	350

- 1 <https://www.vive.com/eu/>
- 2 <https://www.oculus.com/rift/>
- 3 <https://www.playstation.com/fi-fi/explore/playstation-vr/>
- 4 <https://varjo.com/products/vr-1/>
- 5 <https://www.oculus.com/quest/>
- 6 [https://en.wikipedia.org/wiki/Oculus\\_Go/](https://en.wikipedia.org/wiki/Oculus_Go/)
- 7 <https://whatvr.co/compare-vr-headsets/>
- 8 [https://en.wikipedia.org/wiki/Samsung\\_Gear\\_VR/](https://en.wikipedia.org/wiki/Samsung_Gear_VR/)
- 9 [https://www.pico-interactive.com/us/G2\\_4K/](https://www.pico-interactive.com/us/G2_4K/)

Table 1: Comparison of popular virtual reality headsets

From Table 1, it can be concluded that Oculus Quest and Pico G2 4K are all Standalone, with higher resolution and reasonable price, which meet the requirements of this thesis. However, compared with Pico G2 4K, Oculus Quest is more popular because of its development company Facebook. Oculus also provides a lot of developer support, such as development documentation, and there are many development resources on the Internet. It is estimated that the development process of Oculus Quest will be easier than that of Pico G2 4K, so Oculus Quest is chosen as the VR

development platform in this thesis.

### 3.2.2 Software development platform

Oculus supports three development platforms - Unity 3D Engine <sup>7</sup>, Unreal Engine <sup>8</sup>, and Native Development. Among these development platforms, Unity was chosen as the development platform for GRETS in this thesis for the following three reasons:

1. VUTE, the instructional system developed in a previous project [9], used Unity as a development platform. Therefore, the choice of Unity is beneficial for reference and improvement based on the previous development content.
2. Unity uses C# as the development language, which is less complicated than Java, the native development language, and C++, the development language of the Unreal Engine. Moreover, the Unity Learn premium and Unity asset store provides many tutorials and resources for VR content development on Oculus Quest, supporting system design, and development.
3. The author has four years of experience in Unity development and is familiar with the Unity development platform.

In summary, considering the convenience and development cost, Unity 3D Engine was chosen as the development platform of GRETS.

## 3.3 Teaching flow

As mentioned before, the teaching system GRETS is a gamified teaching system for rock engineering education, consisting of a teaching process and an exercise. The teaching materials consist of three parts - teleportation, concepts, and remote measure tool. The teleportation and remote measure tool will be discussed in the next section. The specific teaching flow is shown in Figure 3:

The goal of GRETS is to assist users in learning and understanding the joint set. In order to identify a joint set, users need to measure and read dip and dip direction results, so the joint set is taught by the end of the teaching content. In GRETS, users first learn the dip and dip direction concepts to understand the results of measurements, and then they learn how to use the remote measuring tool to measure dip and dip direction on a virtual rock mass.

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<sup>7</sup><https://unity.com/>

<sup>8</sup><https://www.unrealengine.com/en-US/>

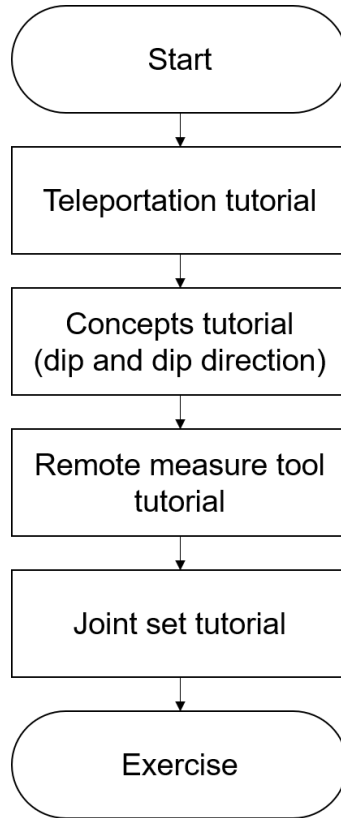


Figure 3: Teaching flow of GRETS

Users face a photorealistic 3D model of a real rock wall located at Karhusaari in Espoo, Finland, in the gamified exercise. They need to analyze the rock structures by measuring dip and dip direction to identify all the existing joint sets. A control system, NGRETS, was created to measure the influence of gamification. More details of gamification are discussed in the next chapter.

### 3.4 Virtual environment design

In VR, users cannot see the real world's environment, so a virtual environment is needed to help them feel "immersed." Given the educational purpose of GRETS, users' attention is likely to be distracted if the virtual environment is too complicated, and the virtual environment needs to be consistent with the educational content. For example, dip and dip direction learning requires reading and thinking. Users may not concentrate on the teaching content if it is a noisy factory or a fancy dance hall. However, a familiar environment such as a classroom with events or actions that are not possible in reality, such as the use of joysticks to control blackboard content, may break users' immersion. Therefore, in GRETS, a tidy, empty white



room with an ambient background sound is chosen as the virtual environment to help users focus on the learning materials.

In the virtual environment center, the interfaces are the teaching materials, which are the major part of the system. Two posters are placed on the room walls as decoration and as hints for the instructional content. One poster is a controller interaction mapping, and on the other controller is a diagram showing dip and dip direction concepts. In GRETS, a badge wall was also placed in another corner of the room to display the badges earned by users.

After learning a series of concepts and measurement methods, the virtual environment center changed from the user interface to the Karhusaari rock wall in the exercise session. Figure 4 (a) is the real Karhusaari rock wall photo from Google map<sup>9</sup>, and Figure 4 (b) is the Karhusaari rock wall 3D model in GRETS. Moreover, blackboard objects were designed around the rock wall as a feedback interface to minimize the awkwardness of the interface and the central 3D object.

### 3.5 Interaction design

The interaction design consists of two main parts. One is a standard interaction method used in VR applications, such as clicking controller buttons and waving controllers. The other is a unique interaction to interact with photorealistic rock body models - remote measuring method.

#### 3.5.1 General interaction design

General interaction refers to the interaction in GRETS except for remote measurements, including interacting with objects in the virtual environment and teleportation movement.

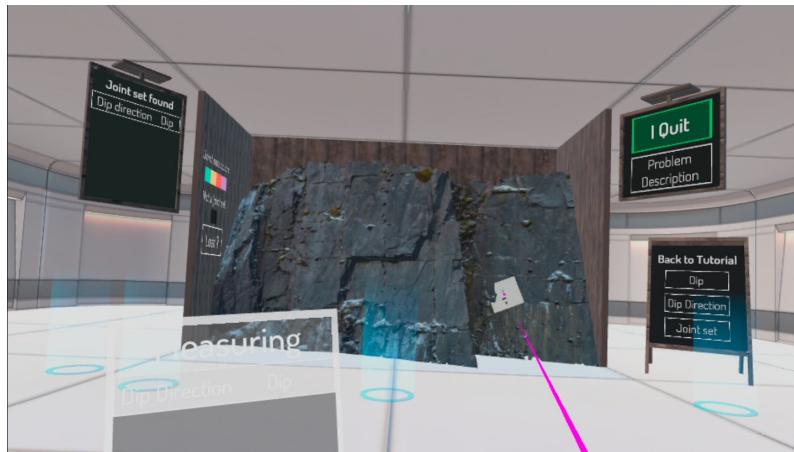
The interaction with objects mainly resides in the interaction design of the instructional content. In GRETS, instructional materials are presented in text, 2D images, and 3D models. Text and 2D images appear as part of the user interfaces, while 3D models appear as part of the environment. The user interfaces are controlled by the buttons on the canvas, as in Figure 5, and the interaction with the 3D model is controlled by the buttons on the controllers. The remote measuring tool is one of the core design aspects of the system and is discussed in detail in the next section. The interaction design follows two primary principles. The first principle is to keep

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<sup>9</sup><https://www.google.com/maps/>



(a) Karhusaari rock wall photo from google map<sup>10</sup>



(b) Karhusaari rock wall in GRETS

Figure 4: Karhusaari rock wall in scenes

the design similar to existing interactions, such as real-life or PC interactions. The hope is to reduce the unfamiliar feeling by replacing with existing interactions that are already familiar to users.

In the virtual environment of VR, the interaction with objects in the environment is unique. Concretely, in the real world, people can interact with real objects by touching, grasping, etc., and receive visual, sound, and tactile feedback at the same time. When using a PC, people interact with files and objects on the desktop by moving the mouse, pointing and clicking, and receive visual, sound, and haptic feedback. When using a screen device, people interact with virtual objects in the screen device by clicking, dragging, flicking, pinching, and receiving visual, sound, and haptic feedback. Similarly, when designing interactions in VR environments, users also need visual, sound, and haptic feedback to support interactions with objects

<sup>10</sup><https://goo.gl/maps/Hsuyo7TZ4qfV1DyLA>

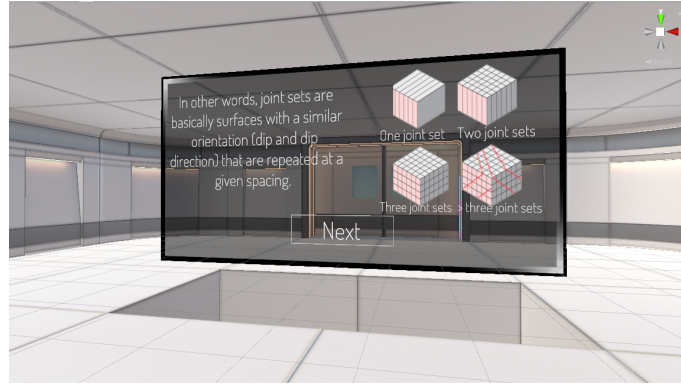


Figure 5: The user interface in GRETS

in the virtual environment. Hence, the interaction design in GRETS is the same as interactions from many VR applications - PC-like interactions using the controller as a mouse. In particular, the primary focus of GRETS is to teach the three concepts of rock mass mapping, all of which require users to see the whole perspective of the rock mass. In the real world, rocks masses are also relatively large objects that are impossible to grasp, pick up. Therefore, impossible interactions such as grabbing have been excluded in GRETS to maintain consistency with the real world.

The second principle is that GRETS is an instructional application on the Oculus Quest, and it should match the native interaction design of the Oculus operating system. Figure 6 (a) shows the user interface interaction in the Oculus Quest operating system, and Figure 6 (b) shows the user interface interaction in GRETS. Specifically, real-time display of grips and buttons, focus dot when aiming at interactive objects, sound, and haptic feedback when aiming at or clicking buttons is transferred to support users make a smooth jump from the Oculus system to GRETS.

The interaction design of GRETS is based on the above design principles. For example, interacting with 2D objects, such as the user interfaces, requires users to use the controller to aim and select with the controller buttons. Interacting with 3D objects requires the user to press the controller buttons to trigger the corresponding actions. And all actions in the virtual environment are providing feedback.

Another thing that makes the VR environment different from the real environment is the way users move around. In the real environment, users can move by walking on their feet and know exactly what is reachable and what is not reachable. For example, in reality, users understand that they suppose to walk to a table, not on the table. However, in the virtual environment, users lack basic knowledge of the reachable



Figure 6: User interface interaction

area and are restricted to a limited physical environment. An approach suggested by the Oculus developer team to solving this problem is to use teleportation - one discontinuous movement method - to move around in the virtual environment with a proper indicator.

The design and development of teleportation in GRETS uses VRTK toolkit (v4)<sup>11</sup>, which is a toolkit for the rapid development of VR applications on Unity. The teleportation interactions in GRETS is the same as VRTK, where users need to use the thumbstick on the right controller to teleport.

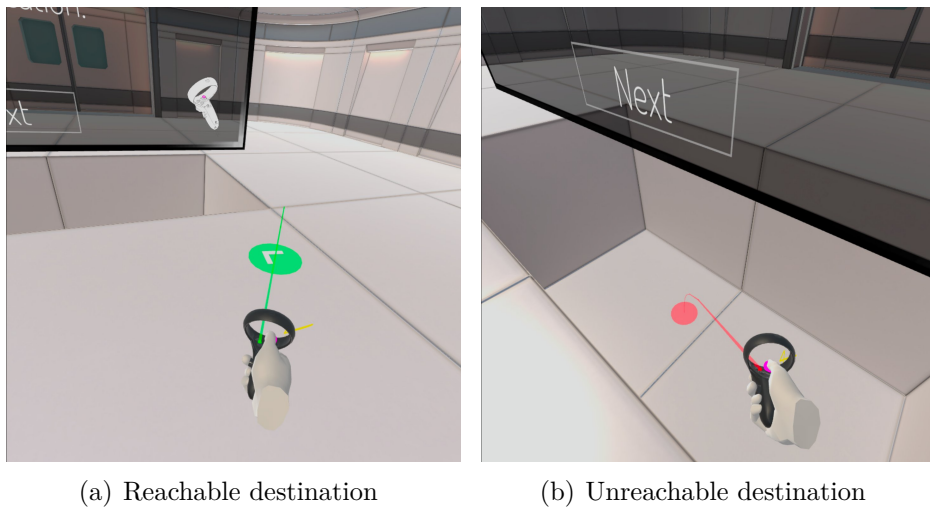


Figure 7: Teleportation indicator

<sup>11</sup><https://github.com/ExtendRealityLtd/VRTK>

As shown in Figure 7 (a), the green circle represents the destination, the white arrow represents the facing direction, and the red circle represents the unreachable location in Figure 7 (b).

### 3.5.2 Remote measuring design

Remote measuring is an interaction to simulate measuring the rock masses in real life. The 3D models in GRETS are scanned in a real environment with photogrammetry [48][11], although some data loss is unavoidable in the digitization process. On the other hand, the 3D model data consists of real data from the rock mass. The remote measuring method is used to virtually measure photorealistic 3D rock models and collect the same measurement data as the real rock mass. The measurement data collected by users in the GRETS exercise is identical to data measured from the rock wall in Karhusaari. According to the previous user study results of the training system VUTE [9], many users wanted to improve the measurement experience of the replica tools. In GRETS, the remote measuring method replaces replica tools for a better user experience.

The remote measuring tool in GRETS is much simpler, more comfortable, and faster to measure than replica tools. With replica tools, as shown in Figure 8, users have to first teleport to the place to be measured, call up the right tool, use tools correctly, write down the data, and move to the submission form. However, with the remote measuring method, users only need to aim at the place they want to measure and press the corresponding button on the controller to get the result.

Briefly, with the remote measuring method, the right controller is used to aim at the measurement point and take measurements, while the left controller is used to review and select measurement data and save data remotely. During the aiming process, an indicator component follows the aimed focus at all times. When users click the finger trigger on the right controller, the aimed point will be measured. After each measurement, an indicator component will appear at the measured point to indicate the measured plane and the normal vector. The measurement result will be displayed on the left controller menu. Users can also select a previous measurement by pushing the left thumbstick. As shown in Figure 9 (a), the indicator component corresponding to the selected measurement will be selected. The color of the indicator will change to green to match the color of the menu result selection.

One reason to replace the replica tools is that the purpose of the instructional application is not to learn how to use the tool to measure correctly but rather to



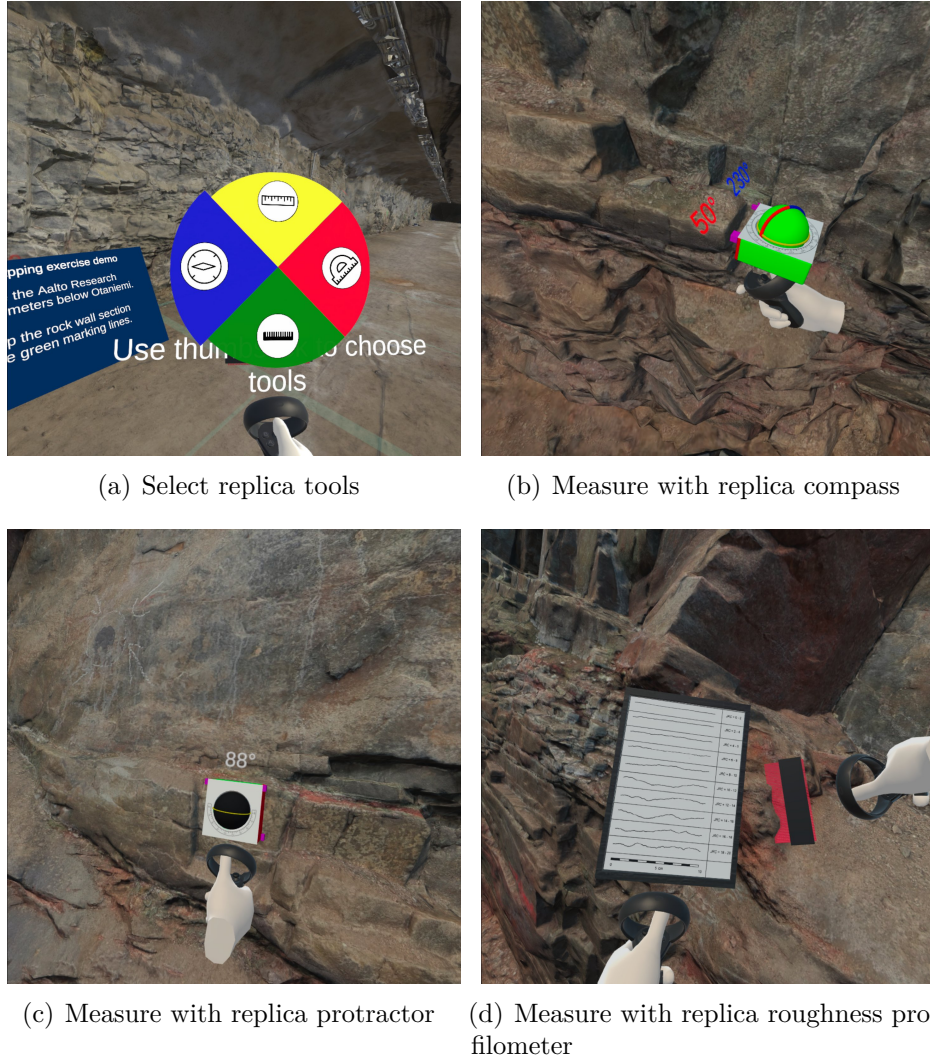


Figure 8: Replica tools used in VUTE

learn the joint set concept through the results of the measurement. If the measurement process is too complicated and tedious, users might become overly frustrated or impressed with the measurement process. Furthermore, users might be distracted from the purpose of the instructional system - learning the joint set and analyzing the measurement results.

Another reason is that users no longer need to make frequent teleportation to reach a location and measure again with the remote measurement. It reduces the number of dilemmas where users are unfamiliar with teleportation and cannot measure the rock mass. Secondly, the remote measuring tool allows users to adjust the viewing angle of the whole rock wall as needed, rather than just a localized view. In other words, the remote measuring method helps users learn the joint set by comparing

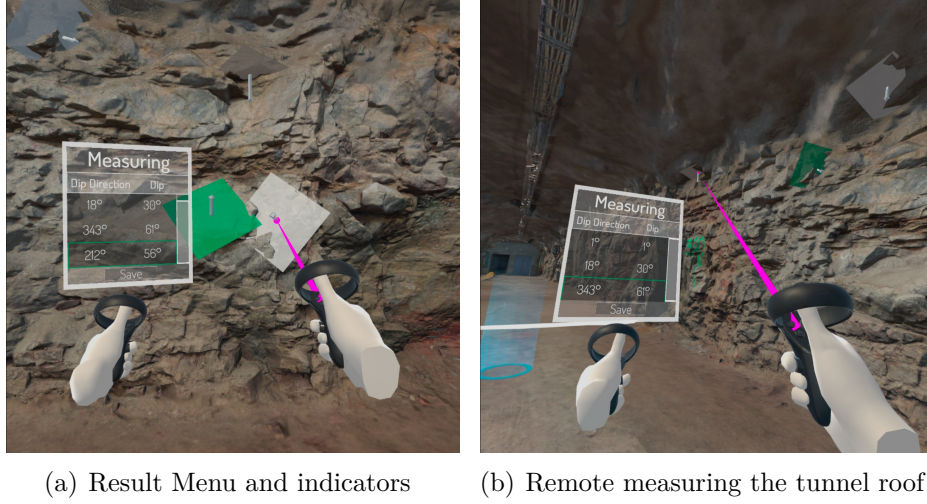


Figure 9: Remote measuring in GRETS

different rock surfaces, rather than teleport to in front of the wall and measuring it and then retreating to compare results. Finally, the remote measuring method makes it easier to measure places that replica tools cannot, such as the roof in Figure 9 (b).

In addition, one purpose of remote measuring is to provide feedback right after each measurement. In GRETS, the data set used as the joint sets comes from real rock scan data. After the photorealistic 3D model was built, an expert uses CloudCompare<sup>12</sup> to analyze the rock mass model and calculate data sets. The data set is shown in Figure 10. Figure 10 (b) shows the point cloud on the 3D model of the Karhusaari rock wall after the rock mass in Figure 10 (a) is divided into joint sets. It can be seen that the entire rock wall is divided into four joint sets: blue, green, yellow, red and a class includes planes that do not belong to any joint set. The specific two-dimensional(2D) stereographic projection and the joint set ranges divided by an expert are shown in Figure 10 (c). The areas enclosed in the colored line frames in the figures represent the value range of joint sets, and the colors of line wireframes represent the corresponding joint set in Figure 10 (b).

However, in practice, it was found that with the existing classification method, each hit is classified as a joint set, which does not match the actual data of the rock mass. As shown in Figure 10 (c), there are many blank areas in each divided joint set collection, and measurements that should not be classified as a joint set are also included in the collection. After further testing with the expert, the final joint set data range used in GRETS is shown in Figure 10 (d) below. The colors and the

<sup>12</sup><https://www.danielgm.net/cc/>

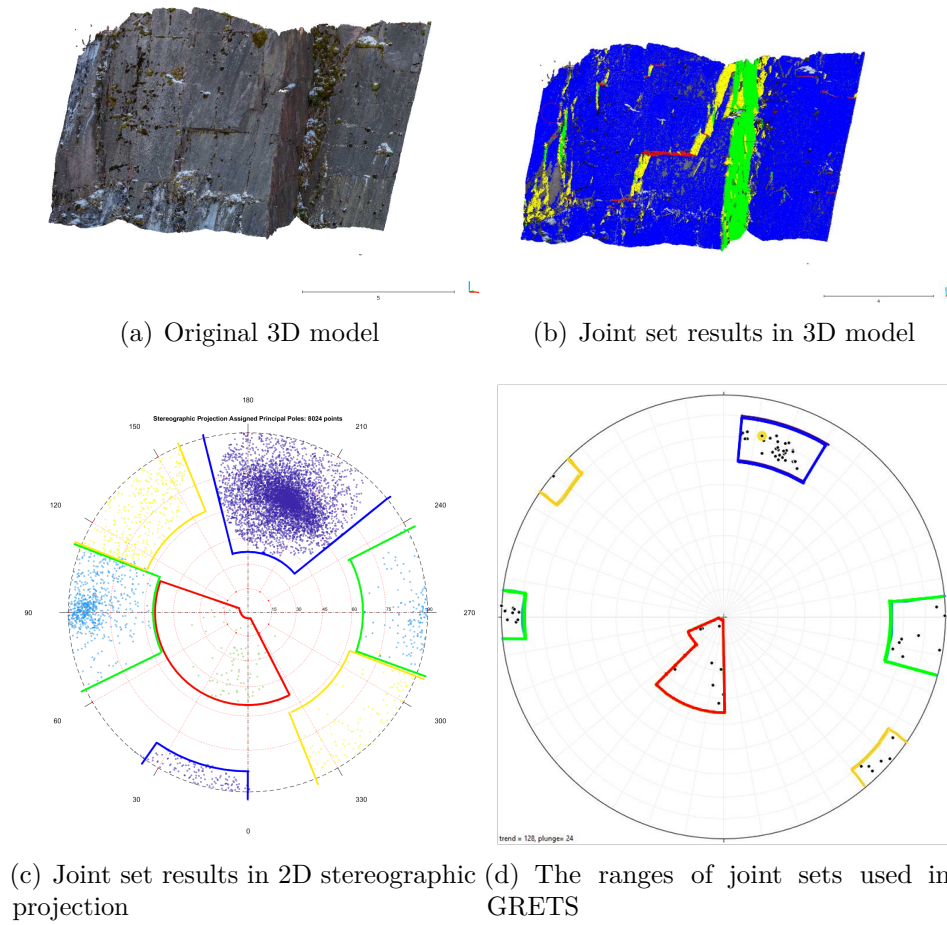


Figure 10: Joint set results

line frames are the same representation as in Figure 10 (b) and Figure 10 (c). It is clearer that the joint set values are narrowed to a smaller range, and after tests, these narrowed ranges provide results similar to real results.



## 4 Gamification design

This chapter discusses in detail the design of the gamified exercise of GRETS and compares it to NGRETS including: the game elements used in GRETS, the detailed design of game elements and mechanics, and the non-gamified system NGRETS.

### 4.1 Game elements

Common game elements used in educational gamification applications include goals, rules, time, rewards, feedback, levels, storytelling, aesthetics, opponents (referring to conflict, competition, or cooperation) [5]. In GRETS, there are six game elements used: goal, rules, time, rewards, feedback, and aesthetics. This section will discuss what these game elements are, what they do, and why they were added and not the others.

Goals are a game outcome, which is either reached or not reached. Usually, goals are also a guiding element in games, and players need to accomplish all goals to win a game. In other words, players have to correctly perform the expected behavior to reach the game's goals. However, unlike teaching objectives, the goals in games are more specific and intuitive. For instance, the teaching objectives of GRETS are to learn the concepts of dip, dip direction, and joint set, then to identify joint sets using the dip and the dip direction. These teaching goals are abstract and invisible to users, and users do not understand how to accomplish them. On the other hand, a game objective is visible and can guide users to hidden educational goals. In GRETS, "identify four joint sets on a rock" is the goal of the exercise, and the "game" ends when this goal is reached. It requires users to learn the concept and map the Karhusaari rock wall structure, thus implicitly accomplishing the educational objectives - learn and master the concepts.

Rules, like goals, are a fundamental element of a game. The rules in a game are always tied to the rewards and goals of the game. When a player acts according to the rules, players are usually rewarded to encourage players to continue following the rules, move closer to the final goal, and get punished when violating the rules. For example, in Super Mario, if players fail to avoid an enemy, their lives will be reduced by one, and they will be forced to start over from the beginning of the level. In other words, players cannot reach their goals if they do not follow the rules.

Time is one of the driving motivators that many games use to push players to achieve their goals. Time can increase the tension, leading to deeper immersion and

engagement in the game, or push players to end exploring, waiting, and performing the expected behavior as quickly as possible. In other words, time, such as a countdown, can pressure players to act by the rules as quickly as possible to reach the goal [5]. There are also games where time is part of the rules, such as in Super Mario, where players will receive punishment and be forced to re-try the level if the level is not completed within the time limit.

A reward is an essential element of game mechanics and is one of the motivating elements that push players to follow the game rules. The types of gamification rewards are points, badges, virtual currency, and avatars [5]. Typically, these rewards are given to players when they perform correct behaviors to encourage them to perform the same behaviors. In other words, rewards can help correct or change the behavior of players. Because of the behavior modification power, the reward is a critical element of a gamified education system. However, studies have also shown that rewards need to be given continuously to ensure that learners are in the reward loop and perform the encouraged behaviors [49]. Once rewards stop, learners may stop making the desired behaviors. The reason is that learners are doing the expected behaviors to get the reward, not because they want to do it. In other words, rewards increase the extrinsic motivation of learners, but not necessarily intrinsically.

Feedback helps players understand the outcome of their actions in the game. There are two types of feedback - informational feedback and juicy feedback [5]. Informational feedback provides players with information about the outcome of their actions, indicating the "rightness" or "wrongness" of the action [5]. Juicy feedback is a continuous flow that makes the result more delicious, prompting players to become more engaged [5]. Examples of common juicy feedback are haptic, sound, and visual effects. When players collect coins in Super Mario, the pleasant sounds and coin-collecting animations are juicy feedback, and the "+1" message overhead is informational feedback.

Aesthetics plays a vital role in a game. Without aesthetics, a game might be dull and flat. The most common aesthetics are visual aesthetics, including fancy characters, dedicated tools, realistic environments, and other visual elements. However, beyond that, aesthetics can also refer to the aesthetics beyond graphics, such as the story and competition. According to the MDA (Mechanics, Dynamics, and Aesthetics) framework, aesthetics are one reason why games are interesting and can evoke expected emotions [50].

The exercise module of GRETS is gamified by adding the above game elements

without levels, Storytelling, and opponents. Levels, Storytelling, and opponents are also excellent gamification elements, but they are not added because of limited time and development ability. Storytelling, which is also an attractive element of many games, is not implemented in GRETS for two reasons: short teaching content and tight development schedule. The stories of teaching three concepts might be too short and require rock education experts to help with the story design. Besides, it takes a long design cycle and much experimentation to design an engaging story, while GRETS has a relatively short design development time (6 months). GRETS had prepared two exercises for game element levels - the Karhusaari rock wall exercise and a virtual tunnel environment. The prepared tunnel exercise is shown in Figure 11. However, due to the limitation of the user test's time duration and the difficulty of the exercises, the tunnel environment could not be utilized in the conducted user tests. Plus, virtual measurement requires the support of photorealistic models, and the current project only has these two available models, which makes it challenging to make more levels for longer gamified experiences. Therefore, the user study setting in this thesis excludes the element levels.

Finally, GRETS aims to provide a self-paced individual learning experience, where the entire learning process can be done by a single learner. It is also hard to share the same view between multiple Oculus quest devices due to the author's development limits.

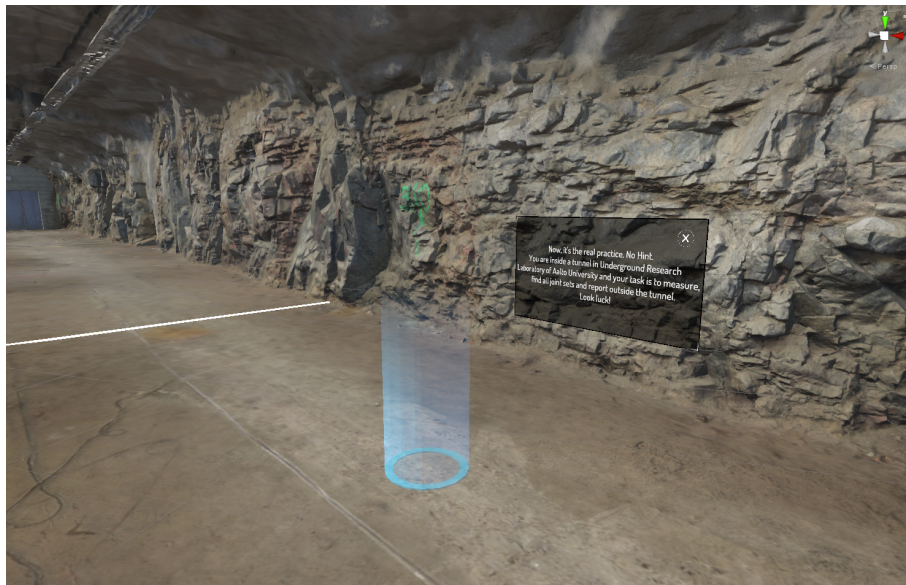


Figure 11: Prepared tunnel exercise

On this basis, GRETS was designed as a single-player gamification application, but

adding opponent elements is one of the future development plans. In fact, in the completed version, a fake competition result - "Better than XX% players" - has been added to the end screen. The current data is calculated by manually entering two extreme values and combining them with player performance, not by the actual player data.

## 4.2 GRETS gamification design

In GRETS, users are asked to measure the Karhusaari rock wall's surface during the entire exercise session, then select and submit the measurements that belong to the joint set until all four joint sets present on the rock body have been identified. The main components representing the gameplay elements from the previous section are the clear goal, messages, graphics, the wrist band, sounds, visual effects, haptic, badges, and the scoreboard.

In GRETS, the clear goal refers to the Karhusaari exercise completion condition - identify all four joint sets, as shown in Figure 12. The clear goal component can provide users with the information for exercise completion methods and the steps (also the mini-goals): measuring and identifying the first, the second, the third, the fourth joint set.

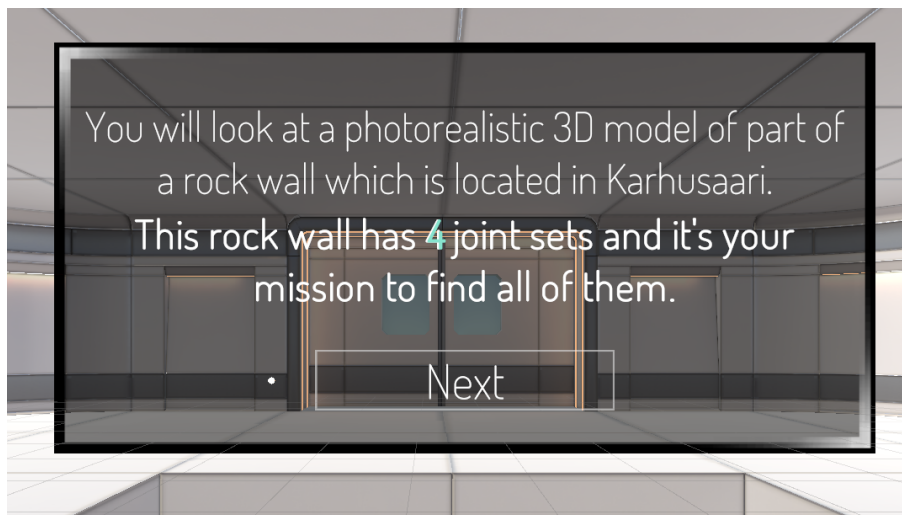


Figure 12: The goal of GRETS exercise

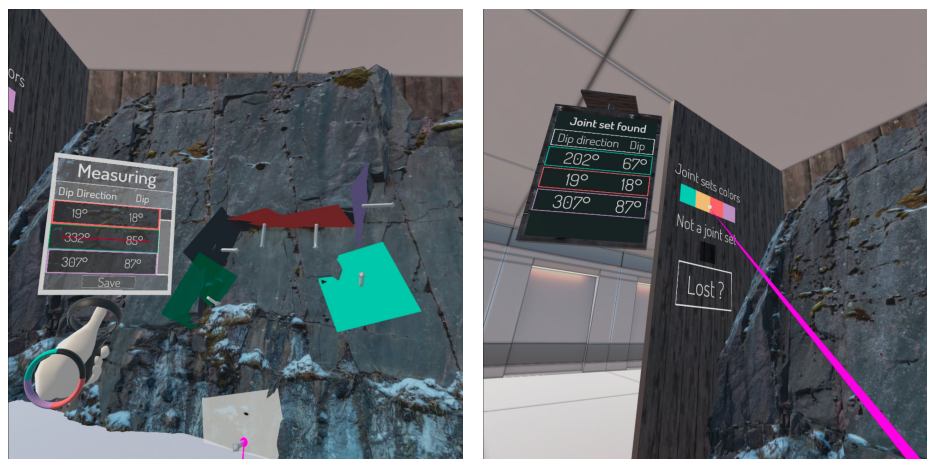
The message is a pop-up notification component in Figure 13 with a delightful sound effect that will appear when one mini-goal is completed. The purpose of the message component is to inform users of the progress they achieved, including a mini-goal that has been reached, how many mini-goals have been reached, and how many

mini-goals are left. The message component is related to the game element feedback, particularly informational feedback, to motivate users in the right behavior loop.



Figure 13: GRETS message component

Graphics here only focus on gamification rather than the virtual environment. The graphics component is mainly associated with aesthetics, feedback, and goals. Aesthetics, including realistic models, badges, and scoreboards, are designed to engage users in the measurement process. Feedback, more specifically, juicy feedback, is the color-tag everywhere. Five colors have been used to represent the current identification status of four joint sets, which is also the mini-goal progress, as shown in Figure 14 (a) and (b). For example, each time a new joint set is identified, the measurement indicator plane, the message component, the measurement results panel on the left controller, the joint set results panel, and the wristband will be marked with the same color. Besides, the color black represents the measurements that do not belong to any joint set, and the corresponding measurement result on the left controller panel will be struck out, as shown in Figure 14 (a).



(a) Measurements, measurement results, wrist band (b) Color indicator and joint set result board

Figure 14: Graphic components in GRETS



The Wrist band in Figure 15 is a progress bar in GRETS that indicates the goal completion status related to the game element goals. It appears at the bottom of the left controller throughout the entire exercise session and filled with the same color as the found joint sets. When all four joint sets are identified, the wrist band will be filled with four colors, and the exercise level will be over.

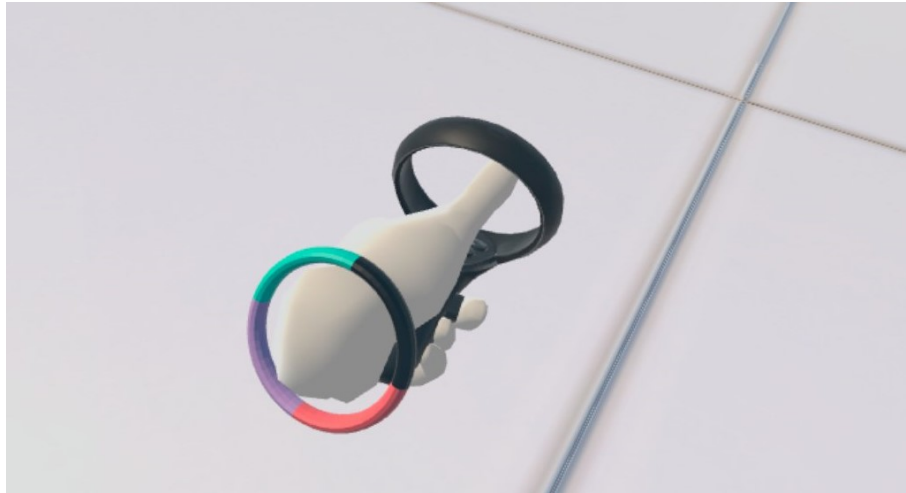


Figure 15: GRETS Wrist band

Various sounds added in the exercise session are divided into two parts: background music and sound effects. The background music changes to rhythmic music from the ambient sound to create an intense atmosphere. The sound effects are used as feedback. For example, if users successfully identified a new joint set, the system gives a cheerful sound effect, while users failed, it gives a depressing sound effect.

Visual effects are primarily used as feedback, but also as aesthetics. When used as feedback, they are always present together with sound effects as juicy feedback. When used as aesthetics, visual effects are used to generate emotions and atmosphere. For instance, the scoreboard that appears at the end of an exercise, visual effects are expected to generate emotions and a winning atmosphere.

Haptic is also primarily used as juicy feedback, and it is only for controller behaviors, including measuring, selecting a measurement, and identifying a joint set. Slightly vibration serves as action feedback, such as button click and measuring a point. It is used to let users notice that actions have been performed. On the other hand, strong vibration serves as feedback and a "punishment" to inform users that the performed behaviors are "wrong."

In Figure 16 (a), badges are a type of rewards element, which appears when users

perform an expected behavior. They are used to motivate users to perform other similar behaviors. A badge appears with other feedback in the center of users' field of view and stays for a few seconds before disappearing. It is automatically collected and will be displayed on a badge wall in the corner of the virtual room, as shown in Figure 16 (b). Table 2 below lists the badges in GRETS and their trigger conditions.

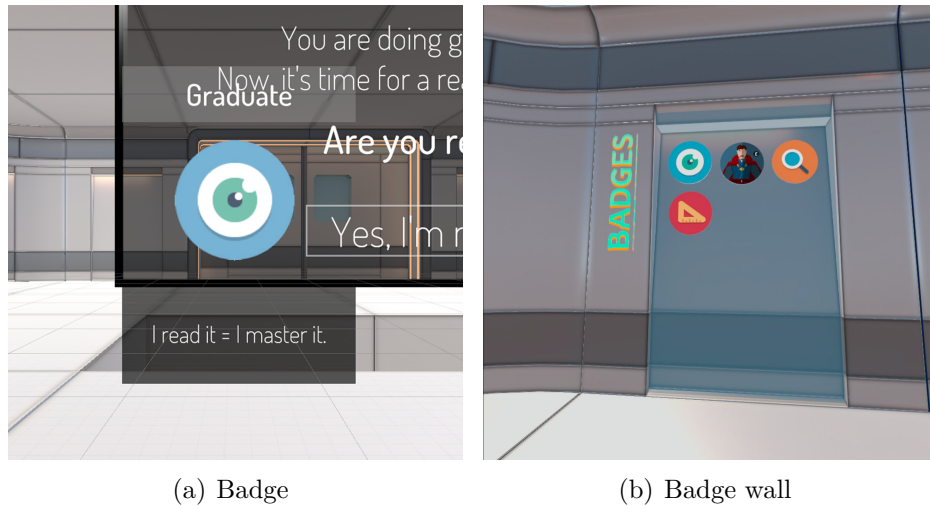


Figure 16: Badge components in GRETS

On the other hand, automatic collection cannot highlight the advantage of interacting with virtual 3D objects using VR, which might benefit the learning experience. Therefore, A new kind of badge - the physical badge - was designed and attempted to replace the traditional badge. The most significant difference between a physical badge and a traditional badge is the collection method. The physical badge requires users to collect them manually.

The scoreboard appears at the end of the entire exercise and is the end screen of GRETS, as shown in Figure 17. It displays the gamified exercise results, including time duration, identified joint sets, fake comparison results with other opponents, and badges. The scoreboard is related to game elements goals, time, rewards.

Above are the gamification components in GRETS. These components are used in the GRETS exercise sessions, thus achieving gamification. The gamification experience in GRETS is slightly different from a regular game due to the VR environment and teaching content. More detailed results on the badge performance are discussed in chapter 5.3.3.

Badges Name	Condition	Description text
Dr.Strange	First teleport	Is that a Sling Ring?
Level 01	Make first measurement	Ok... looks like we got something
Sharing	First save	Friend with a sharing mind
Explorer	Identify first joint set	Do or do not. There is no try.
Graduate	Finish tutorial	I read it = I master it.
Yoda	Identify all joint sets Karhusaari rock wall	May the force be with you.
Becoming expert	Make 50 measurements on Karhusaari rock wall	The shining new star of Rock engineering
Patience	Go back to tutorial	Do it again when you are not sure
Too much	Submit 20 measurements of one joint set	Stop it. Go and find another joint set.
Level 100	Make 100 measurements on Karhusaari rock wall	You are on fire!

Table 2: Badge design details

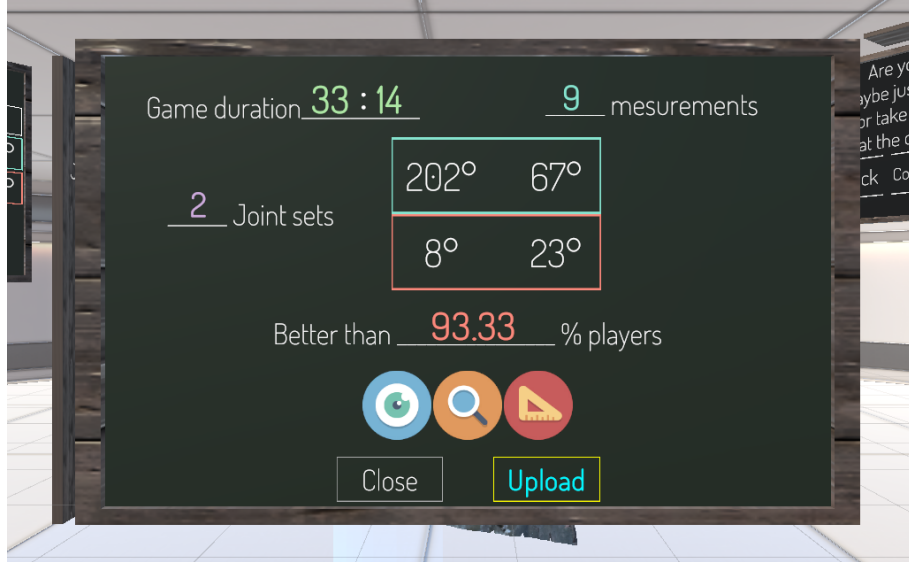


Figure 17: GRETS Scoreboard

### 4.3 Physical Badge

The physical badge is a content-related reward type developed for this thesis. Many gamification applications use the same or similar rewards to gamify different educational content [1]. With the physical badge design, GRETS is trying to highlight the



VR platform's unique advantage and maximize its teaching outcomes. The teaching outcome here essentially refers to the intrinsic motivation and subjective feelings of learners. As mentioned before, the physical badge is a kind of badge that has a unique collection method. Concretely, instead of an automatic collection, a physical badge will physically exist in the virtual environment, and users need to collect it manually. After it is triggered, a physical badge will appear near users, including a disk that cannot be teleported on (Figure 18 (b)) and the badge itself (Figure 18 (a)). To collect the physical badge, users need to teleport near the disk, move with their feet or stretch out their arms, and "touch" the physical badge with both controllers, as shown in Figure 18 (c). Then the physical badge will be successfully collected.

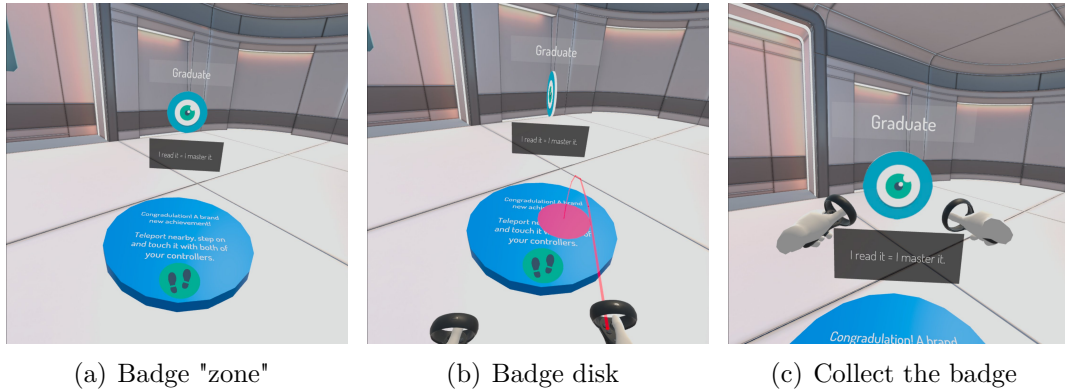


Figure 18: Physical badge

The physical badge is designed by pushing users to perform a particular body movement different from other body movements performed when using the system. In detail, when using GRETS, users do not move with their feet or stretch their arms to reach an object, except collecting physical badges. It is expected to enhance immersion and emotion through the particular body movements, thus promoting intrinsic motivation.

It has been studied that body movement facilitates game element aesthetics in three ways: enhancing fantasy, communication, and effectiveness [51]. The physical badge was designed to increase the body movement user performed in GRETS in order to improve game aesthetics. In this thesis, a short user study was conducted to evaluate physical badges and measure the influence of physical badges on the learning experience. As a result, the traditional badge is chosen as the reward element in the final GRETS. However, the user study results also raise some interesting points, such as the possibility that physical badge has more powerful behavior modification capabilities. The short user study results will be discussed in detail in later Evaluation

section 5.2.3.

## 4.4 NGRETS

NGRETS is a control system created to measure the influence of gamification. In this system, all game elements are excluded except the goal. The goal of the NGRETS exercise session is changed from the "find four joint sets" to "find all joint sets." Also, instead of automatically end, the exercise session requires manual submission. Users cannot see the details of joint sets, including how many joint sets have been identified, which measurements belong to a joint set, until they submit, in other words, end the exercise session. After users submit their measurements, a result board will appear with results, and all measurements will be classified according to joint sets. The process of non-gamified exercise is shown in Figure 19. However, NGRETS keeps necessary interaction feedback, such as sound and vibration feedback when clicking a button or measuring.

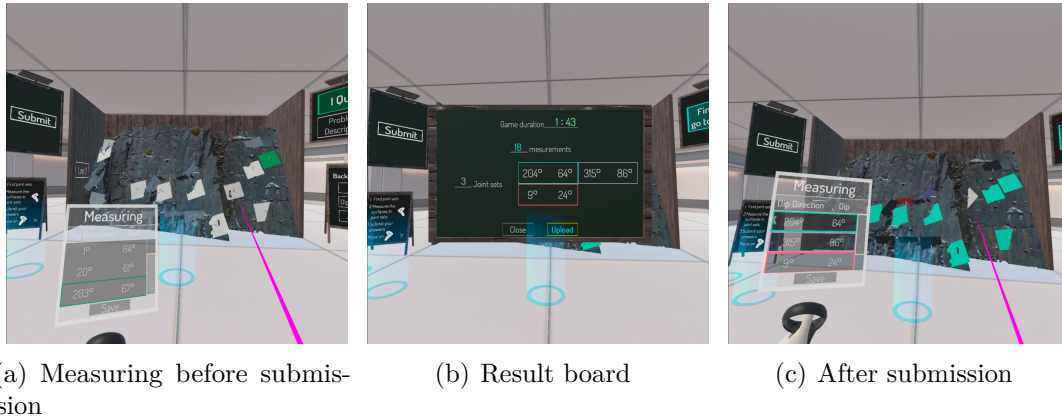


Figure 19: NGRETS exercise

The exercise of NGRETS is designed to simulate an exam, so learners do not know the result until the end of the exercise, and they only have one chance to submit their measurements. Figure 20 shows the workflow of the exercise section in GRETS and NGRETS. The main difference is the cycle process. In Figure 20 (b), the NGRETS exercise workflow is one-time submission while GRETS allows learners multiple tries and provides feedback.

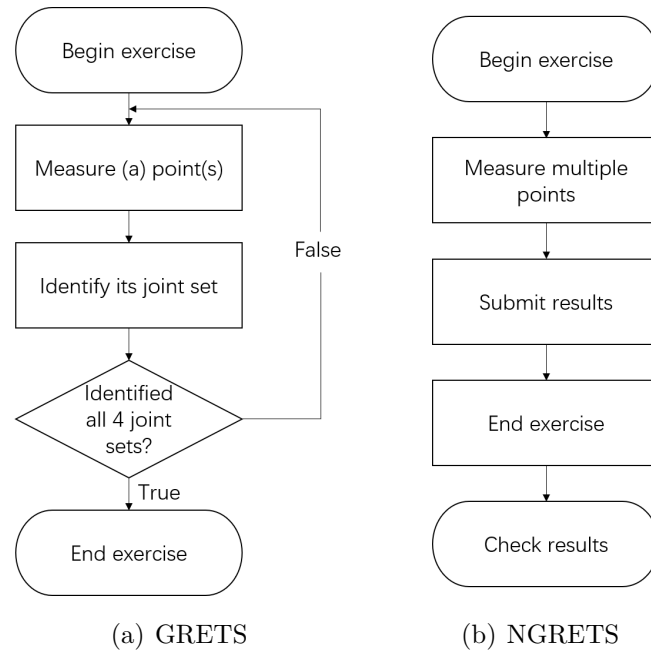


Figure 20: Exercise flowcharts

In Conclusion, NGRETS exercise is designed to be an interactive, non-gamified exercise. It is used to compare with the gamified GRETS exercise to measure the impact of gamification on the user experience and learning outcomes.

## 5 Evaluation

This chapter describes the design and implementation of the user study, including the target group, the two-round within-subject user study, and the results.

In this thesis, the user study was divided into two rounds. The first round was a within-subject user study comparing the performance of traditional badges with physical badges to identify the better rewards of GRETS. The second round of user study was also a within-subject user study comparing GRETS and NGRETS to measure the impact of gamification. At the end of each test, participants were offered a small bag of candy or a chocolate bar as a gift for their participation.

There are two reasons for choosing the within-subject experiment. First, participants' preferences for the reward type need to be collected, and the within-subject user study allows participants to compare the two rewards without being influenced by other factors. Second, time limitations and social distancing due to the COVID-19 pandemic [52] made it challenging to reach a large number of users for testing, and choosing the within-subject user study reduces the number of participants required.

### 5.1 Target group

GRETS is designed to help users learn and master the three concepts in rock structural mapping repetitively at their own pace. The three concepts are dip, dip direction, joint set in rock structural mapping. The target user group of GRETS is people who need to learn rock structural mapping, including master students whose major is rock engineering.

### 5.2 The first round user study

The first round of the within-subject user test focuses on the reward design. The research problem of the first round is which of the two reward designs, the traditional badge or the physical badge, leads to a better user experience. The hypothesis is that the physical badge leads to a better user experience, and the independent variable is the reward design.

#### 5.2.1 Participants

Four participants (N=4, three male and one female) were involved in the first round of user testing. The participants' mean age was 26 years (median = 26 years old,

SD=1.83 year), the minimum age was 24 years, and the maximum age was 28 years. The mean duration of the GRETS experiment for each participant (N=3, one participant's time data was missing due to the network) was 30.32 minutes (median = 33.89 min, SD = 9.44 min). Three participants are master students from Aalto University, and all four participants do not major in rock engineering. All four participants had no prior knowledge of the rock engineering concepts in GRETS.

### 5.2.2 Methodology

In this round of user study, participants are exposed to two different variables in random order, and the manipulated variable is the reward design. Under each condition, quantitative and qualitative data are collected. The quantitative data is collected from the UPEQ, a 5-point Likert scale questionnaire to analyze the motivational affordance in different conditions. In detail, 16 questions in three subscales (6 questions for autonomy, 6 questions for competence, 4 questions for relatedness) were used in this round. Although the responses to subscale relatedness were collected, this thesis focuses on subscale autonomy and competition because GRETS is a single-player system. The detailed questionnaire content is listed in Appendix A.1. The qualitative data was collected from observation while using the system and interviews at the end of the test. Interview questions include the preference for the manipulated variables, the learning outcomes of the instructional system, and the perception of using the instructional system. The detailed interview questions are listed in Appendix A.2.

Figure 21 describes the procedure of the first round user study. At the beginning of the test, participants were informed of the test content, and dice were rolled to determine the conditions' order. Under each condition, participants were asked to do the same tasks. They first learned the teaching content and then completed an exercise session. However, to reduce the influence of re-learning, participants were told to skip the content and go straight to the exercise in the second condition. The testing time was 60-80 minutes per participant, and the test locations were familiar places of the participants, such as their homes. One or two people who knew each other, such as roommates, were divided into one user group under the participants' consent. Figure 22 shows the experiment setting and how users were interacting with the systems.

Among the four participants, as a result of the dice roll, two participants were first exposed to the system designed using the traditional badge, while the other two were

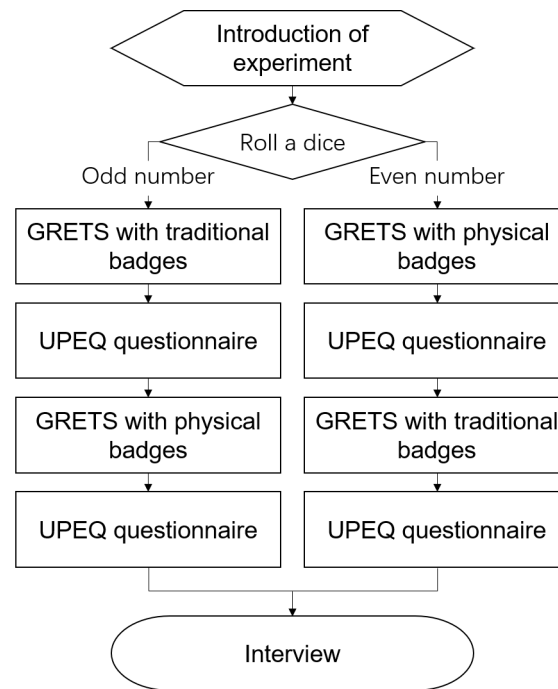


Figure 21: First round user study procedure



Figure 22: A participant is doing user test

first exposed to the system designed using the physical badge.

### 5.2.3 Result

#### Users have problems towards VR content

During user testing, three participants found teleport difficult and sought additional help from the researcher during the testing process, and two participants even had to

turn frequently to adjust their orientation in the virtual environment. One possible reason is that teleportation is a unique movement method of the VR platform. Participants were not familiar with teleportation, and there was still a gap between the textual instructions in GRETS and required actions. Three participants did not understand how to identify a joint set during the practice session, even though they had just finished reading the instructions. None of the participants noticed that the colors of the indicators corresponded to the different joint set results. Besides, two participants reported the notification disappeared before they finished reading.

### **Users are excited when interacting with GRETS**

All participants expressed some degree of negative emotions while teaching the concepts, such as sighing and asking questions. In the interviews, participants mentioned that this was because there was too much text to read in GRETS and that the concepts taught were obscure and entirely unfamiliar to them. One possible explanation is that participants were expecting a game session rather than a teaching section during testing. Therefore a certain sense of frustration was generated when they had to learn. At the same time, however, all participants reacted with surprise or excitement when given a badge in GRETS, such as light laughter. Besides, all participants finished the test in a relatively exciting state, with symptoms like talking a lot and continually making comments. One participant unconsciously laughed to himself when he was unable to find the last joint set, and one participant took off the VR headset with his face blushed after using GRETS.

### **Users show unique behaviors on physical badges**

Moreover, when using GRETS with traditional badges, one participant did not notice badges from start to finish. One participant reported: "(I) don't know what happened." During testing GRETS with physical badges, one participant collected only one badge and then stopped collecting it, leaving the physical badge scattered in the virtual environment. One participant kept turning his head to find the location where the physical badge was generated. One participant triggered several physical badges before starting to collect and stop measuring until all badges were collected. Another observation is that two participants who handled the physical badge first attempted to use the physical badge collection method to collect traditional badges during the other test. Here, the physical badge demonstrates more powerful behavior modification capabilities. However, the behavior modification capability of badge types was not measured, and this inference cannot be confirmed from the behavior of the two participants alone. A follow-up user study is needed to research on behavior

modification capability of different badge types. If this inference is confirmed, combining the teaching content and the physical badge will be a good method for teaching and correcting learners' behaviors.

### **Traditional badge and physical badge have similar performance in intrinsic motivation**

The UPEQ questionnaire results were divided into three components according to SDT theory, and Figure 23 shows the comparison of the results of the two badges. The green box represents the traditional badge results, and the purple box represents the results of the physical badge. There was little difference in autonomy and competence between the two badge designs from the box plot.

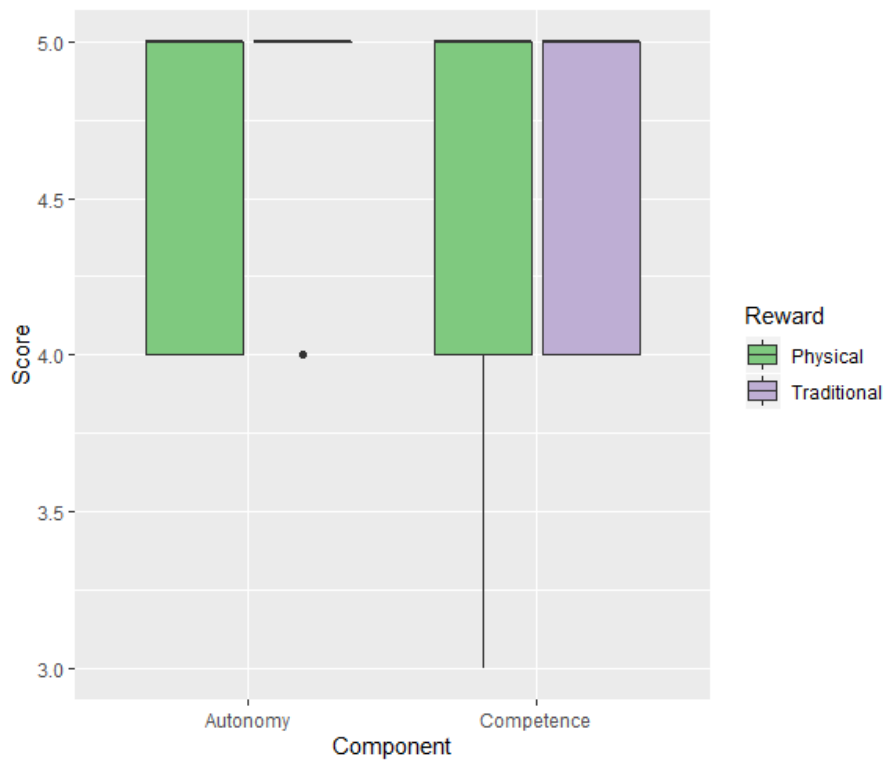


Figure 23: First round user study UPEQ questionnaire component results

As shown in Table 3, the median and mean scores of both badge designs were greater than 4.5. The performance of two badge designs was quite similar, according to the UPEQ questionnaire results. In general, both badge designs fulfilled participants' autonomy, and participants felt competence during the interaction. In other words, participants had high autonomy and felt that they were able to control GRETS through their actions. Participants also felt competent during interacting with GRETS and consider all tasks were capable of performing.



	Mean	Median	SD
<b>Autonomy(T)</b>	4.79	5	0.41
<b>Competence(T)</b>	4.67	5	0.48
<b>Autonomy(P)</b>	5	4.63	0.49
<b>Competence(P)</b>	5	4.58	0.72

Table 3: First round user study UPEQ questionnaire component scores

### Users prefer traditional badges

Two participants preferred the physical badge because it demonstrated *"the feature of VR"* and *"at least I noticed,"* comment by participants. On the contrary, two participants preferred the traditional badge because it was *"easy to get,"* while the physical badge *"interrupts measuring."* Overall, participants considered the physical badge to be a unique and new design, which required more attention regards collection. The physical badge help participants notice the badge's existence and acquisition. However, at the same time, this manual collection method of physical badges interrupted the measurement process, which is the primary process of the exercise. Participants described this manual collection as *"extra action"* and *"not necessary."* Three participants considered measuring and identifying joint sets as the most important task. In order words, the physical badge did not affect the joint set results but interrupted the process of completing the exercise. One participant commented that the physical badge was *"new,"* but *"one-time experience is enough."* On the other hand, participants did not comment much on the traditional badge. As reported, they preferred the traditional badge mainly because of the physical badge's disadvantages. Although the physical badge brought novel interaction methods, it was not mature in its design and stability, thus degraded the GRETS user experience.

### Users are not motivated by badges

In addition, unexpectedly, three participants mentioned badges, whether physical or traditional badges, were not the motivator. One participant said he continued to accomplish the goal, while the other two said the wrist band (progress bar) was their motivator. One participant mentioned that the wrist band's color change and the notifications made him excited because it indicated he was doing the right thing.

### 5.3 The second round user study

The second round of user study within-subject focused on the impact of gamification on the user experience of the instructional system. The hypothesis in this round is that gamification can improve the learning experience and learning outcomes of the instructional system. The manipulated variable was the existence of gamified content, and the within-subject user study is still selected for the same reason as the previous round. Besides, problems identified in the first round were modified. For instance, color indicators were added to inform users about the meaning of colors and notifications. The interview question: "what motivates you to continue learning? (for each game)" was added to measure the exact motivator of continuing learning.

#### 5.3.1 Participants

A total of 10 participants ( $N = 10$ , 5 female and 5 male) were involved in the second round of user testing. The participants were 25.2 years old on average (median = 24.5 years old,  $SD = 2.49$  years), the minimum age was 22 years old, and the maximum age was 29 years old. All students were from Aalto University. Two participants reported that they had heard of the concept before. One participant read about it from technical blogs and websites, and the other took a course on the concept during her undergraduate study. The remaining eight participants had never heard of the concepts.

#### 5.3.2 Methodology

The participants were exposed to two different variables in random order, and under each condition, quantitative and qualitative data were collected. Quantitative data was the same as the first user study and the addition of participant behavior data collected from both systems. Precisely, the duration of the participant's exercise session, the measurement results, and the acquisition of badges were collected with the consent of participants. The data were used to evaluate how gamification could change the behaviors of the participants.

The qualitative data was the same as the first round of the user study. However, the questions in the interviews were adjusted to add about gamification, such as which kind of game elements were more motivating, and if they wanted to turn GRETS into a multiplayer game. Detailed interview questions are listed in Appendix A.2.

As described in Figure 24, at the beginning of the test, participants were informed of

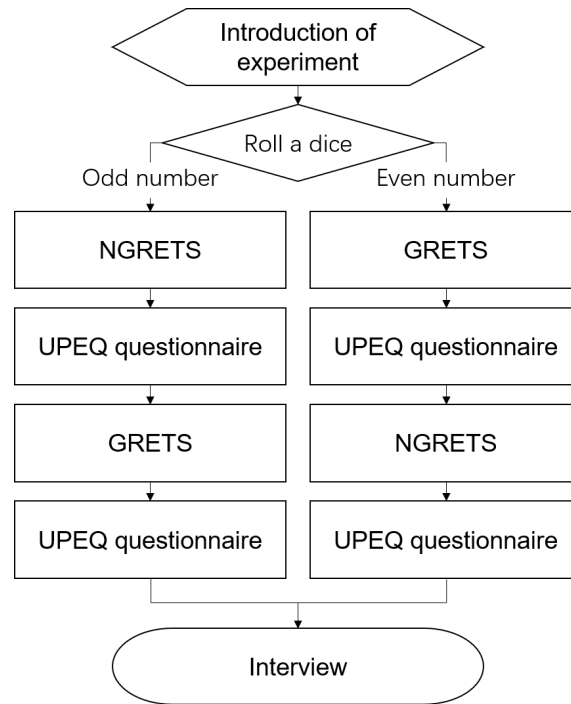


Figure 24: Experiment flow

the test and were asked to roll the dice to decide the order of the conditions. The participants were asked to do the same tasks for each condition and upload their behavior data after completing the exercise. Other experiment settings were the same as the previous round user study.

### 5.3.3 Result

#### Users have problems about VR content

In the second round of user testing, as in the previous round, participants gave similar negative comments towards VR teaching content, such as teleportation, reading text. Six participants had difficulties with teleportation, including mistakenly triggering teleportation and controlling facing direction. One participant even had to use both hands for teleportation to teleport to an accurate position and direction. One participant described that teleportation was an *"anti-intuitive"* way of moving, which gave him a bad experience. Another repeated problem was the excessive use of text during the conceptual teaching module, which three participants mentioned. One participant commented *"I don't know why I'm reading in VR," "it's (texts) pixelated,"* and another commented, *"it's like reading a textbook."* Consistent with the previous test, most of the participants sighed when they realized they needed to

spend time reading text for learning. One participant said, *"learning is tiring"* when noticing the instruction text.

In addition to the problems similar to the previous round of user tests, participants also reported new problems. Three participants reported that they forgot the actions while interacting with the system, and one participant said: *"I can't remember the (corresponding) buttons."* Even though there was a prompt interaction panel in the form of posters in the environment, no participant was aware that they could use them. Instead, they relied on the researcher's responses to find the buttons. Besides, six participants mentioned various levels of discomfort when wearing the VR device, mostly mild, such as the headset is *"too heavy," "eyes are a bit hurt."* *"can I sit down to test?"* However, two participants quit the exercise due to discomfort, and one participant had to use her left hand to hold the headset to continue the experiment. Both of them did not feel discomfort when they were tested after re-wearing. One of them asked to retry the part she gave up at the end of the experiment and described her learning experience as *"very pleasant."* Considering that the participants were unfamiliar with the VR device and wore it the wrong way, the discomfort could be reduced by re-wearing or adjusting it. The last issue was that three participants mentioned they had difficulty measuring particular points during the exercise session because the pointer moved when they clicked.

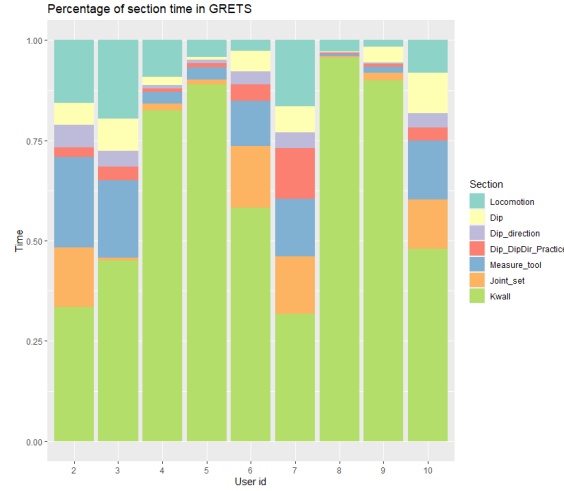
### **GRETS is gamified**

Participants were asked the question: "Do you think the gamified system counts for a game?" Eight out of ten participants consider GRETS as a game. One participant commented that he was *"feeling like solving a puzzle"* when using GRETS. Only two participants took GRETS as not a game because of the lack of levels. *"It's too short and many concepts to learn,"* said one participant. *"There are no competitors, no deadlines, no levels,"* said the other participant. However, all participants talked about game elements such as feedback, goals, and rules during interviews. Hence GRETS was considered gamified because the game elements served the content as participants agreed. Moreover, by adding more content or levels, GRETS will fit the game's standard for all participants.

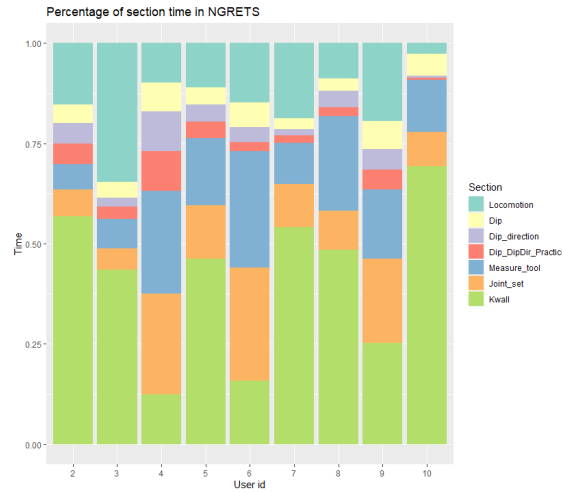
### **Gamification can increase users' practice time**

By collecting each section of the participants' start and end time using GRETS and NGRETS, each section's time duration was calculated. The average duration ( $N = 9$ , one participant lost quantitative data due to accidental operation) interacting

with the VR teaching systems was 35.90 min ( median = 28.88 min, SD =14.88 min), excluding the time spent on questionnaires and interview.



(a) Percentage of section time in GRETS



(b) Percentage of section time in NGRETS

Figure 25: Percentage section time in GRETS and NGRETS. Sections includes (in order of use): locomotion, dip learning, dip direction learning, dip and dip direction practice, measure tools tutorials, joint set learning and Karhusaari rock wall exercise.

As shown in Figure 25, the green part Kwall represents the Karhusaari rock wall measurement exercise (the same below), which is clearly the largest portion of the participant's system duration. Under the gamified condition, Kwall exercise accounted for an average of 34.25% (median = 35.67%, sd = 7.65%) of the entire system usage time, while under the non-gamified condition, the average percentage of Kwall exercise was 25.60% (median = 20.56%, sd=14.10%). It shows that participants

focus more on the exercise section in the gamified condition.

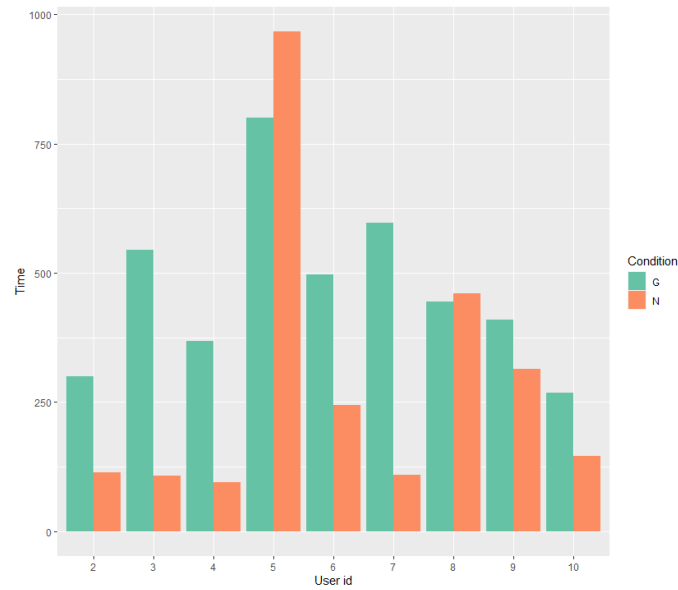
To further reduce the impact of the condition order, such as re-learning, Kwall exercise duration time was compared alone between conditions. Figure 26(a) shows the duration of the Kwall exercise under two conditions, where the unit of time is seconds, G stands for condition Gamified, and N stands for condition Non-gamified (the same below). The average duration of the Kwall exercise was 426.98 seconds (median = 421.98 seconds, sd = 167.19 seconds) in the gamified condition and 416.11 seconds (median = 313.88 seconds, sd = 334.83 seconds) in the non-gamified condition. It can be seen that participants in the gamified condition spent on average more time in the Kwall exercise compared to the non-gamified condition, while only participants number 5 and 8 spent more time in the non-gamified Kwall exercise. Figure 26 (b) shows the difference in Kwall exercise duration corresponding to the condition order. The time diff was calculated according to Formula (1). The time difference ( $T_{diff}$ ) equals the time spent in the Kwall exercise under the first condition ( $T_{first}$ ) minus the time spent in the second condition ( $T_{second}$ ) by each participant, in seconds.

$$T_{diff} = T_{first} - T_{second} \quad (1)$$

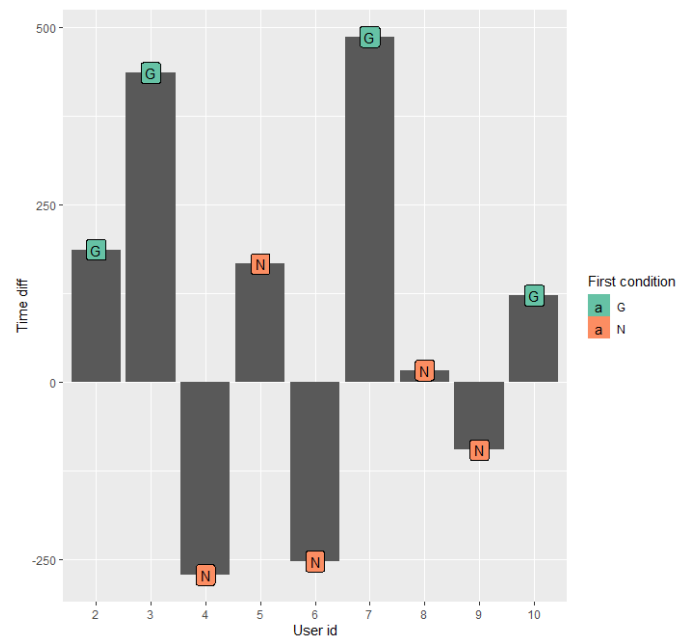
In Figure 26 (b), most of the participants spent more time in the gamified Kwall exercise, and only participants 5 and 8 spent more time in the non-gamified Kwall exercise, which was the first condition. Considering that participants were more familiar with the exercise content after the second condition, which might reduce the duration of use. Hence, the result was interpreted that gamification can increase the length of time users spend on the teaching content.

**The users' measurement results in the system are consistent with the real-life teaching situation.**

During the teaching of the three concepts, participants spent more time on the concept of joint set. An average of 44.50% (median = 48.27%, sd = 18.01%) of concept learning time was spent on joint set learning. Figure 27 shows the concept learning time distribution of each participant at the first learning (under the first condition). This result was consistent with a real teaching environment. *"It is expected,"* commented by Postdoctoral researcher Mateusz Janiszewski, who is the advisor of this thesis and is responsible for assisting the field exercises of the Engineering geology course at Aalto University.



(a) Kwall time duration of conditions



(b) Kwall time difference of condition order

Figure 26: Kwall time duration differences between conditions

In the Kwall exercise, the stereoplot of the participants' measurement data is shown in Figure 28 using software Stereonet<sup>13</sup>. The green dots represent the measurement data under the gamified condition, and the orange dots represent the measurement data under the non-gamified condition. Figure 29 shows the total number of times each

<sup>13</sup><http://www.geo.cornell.edu/geology/faculty/RWA/programs/stereonet.html>

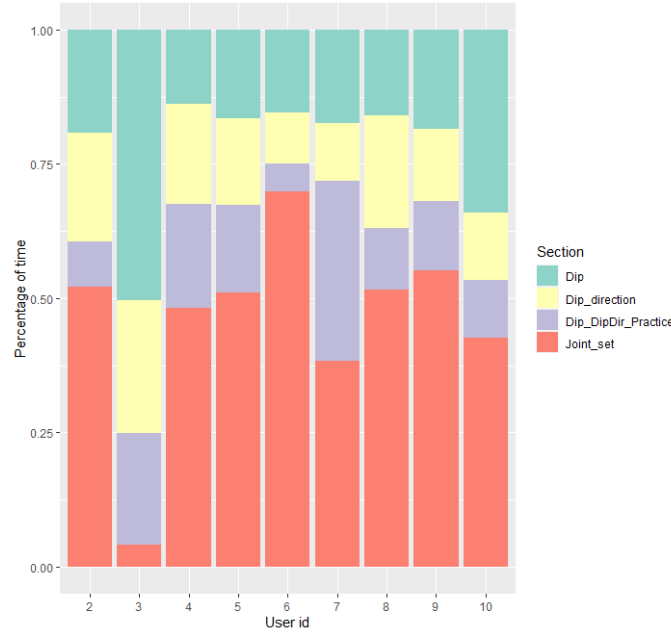


Figure 27: Percentage of concept learning duration

joint set was identified. The Js1, Js2, Js3, and Js4 marked on the x-axis correspond to the blue, green, red, and yellow joint set collections in Figure 28. Not\_Js means that the measured data does not belong to Any joint set collection. Comparing Figure 10 (b), we can see that the participants' measurement data in the virtual environment matches the real data. For example, the blue joint set collection has the largest distribution area on the rock mass, and the number of times identified by participants in the virtual environment was also the largest. On the other hand, the red joint set collection has the least distribution area on the rock mass, and the total number of identification times was also the least.

### Users have higher accuracy index in the gamified exercise

Based on existing measurements, a statistical variable capable of describing the correct rate of participant identifications needs to be defined to more intuitively compare learning outcomes across participants. As shown in Formula (2), it was attempted to describe the learning outcome by the correct rate (R), which requires the number of successful identifications ( $N_{Identifications_{JS}}$ ) divided by the total number of measurements ( $N_{Measurements}$ ). In practice, however, the correct rate is not a substitute for the true learning outcome. Concretely, assuming a user measured 8 times, and all 8 of which belong to joint sets, his correct rate was 100% calculated by Formula (2). In fact, the difficulty of identifying each joint set differs due to



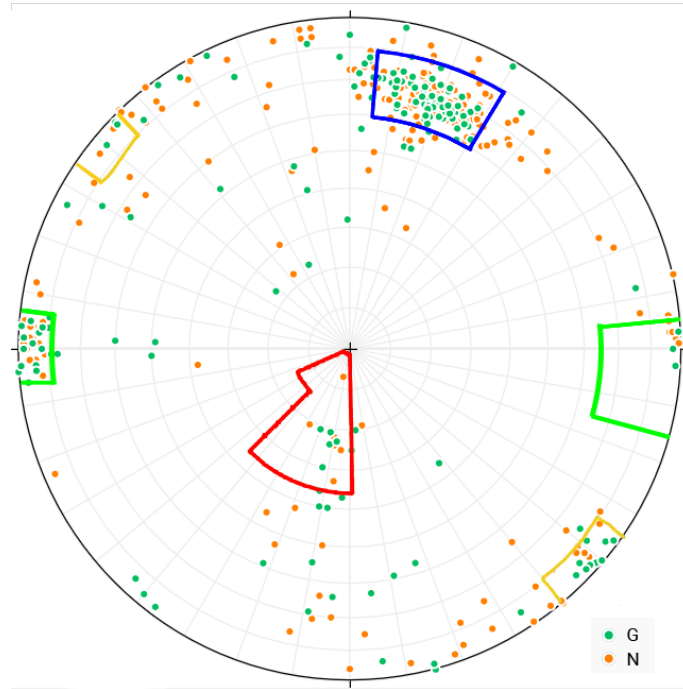


Figure 28: Measurement results of participants

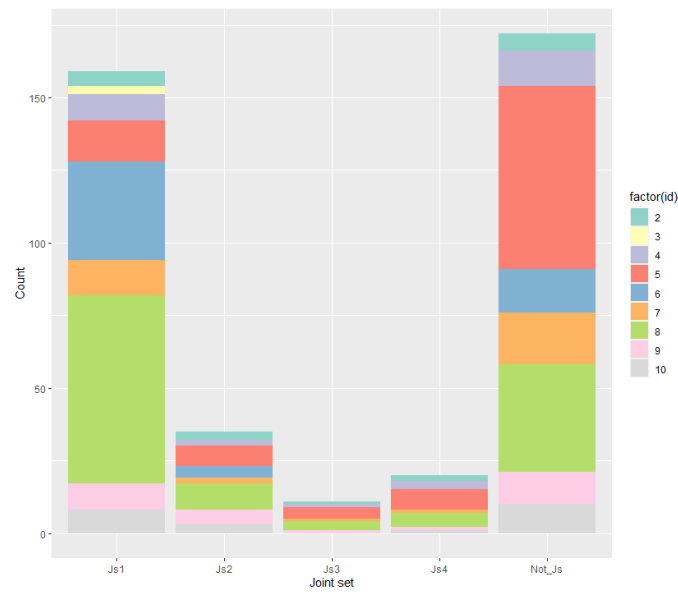


Figure 29: Sum of the number of measurements identified as a joint set

its area of the rock body (see Figure 10(b)). In detail, the data analysis result of CloudCompare on the rock mass model shows that a total of 1140218 points belong to joint sets. The detailed point cloud results and proportions are shown in Table 4 below. Large point counts indicate that the corresponding joint set has a large area

in the rock mass and is easy to be identified. If the user identified all 8 times the easiest blue joint set, his correct rate was calculated to be 100%, but he might not identify all the joint sets, which means he did not reach the exercise goal.

In order to balance the influence of identification difficulty, this thesis weighted Formula (2) according to the distribution area of the joint sets and came up with the calculation method of accuracy index (I) in Formula (3), where the sum of  $N_{Identifications_{js1}}$ ,  $N_{Identifications_{js2}}$ ,  $N_{Identifications_{js3}}$  and  $N_{Identifications_{js4}}$  is  $N_{Identifications_{js}}$ . The difficulty coefficient weight  $\omega_n$  is calculated according to Formula (4), and the results are shown in Table 4. The  $p_n$  of Formula (4) represents the proportion of the joint set's distribution area, which is also the percentile data in Table 4. The accuracy index value is always greater than 0, with larger values representing better learning outcomes when less than 0.25 in this thesis. In particular, when the accuracy index is 0.25, all the joint sets are equally identified, which is the ideal identification result. For example, when the user measured 8 times, and all 4 joint sets were identified twice, the accuracy index took the value of 0.25, representing that the user performed the ideal identification behavior. It should be emphasized that the accuracy index is only a statistical variable to evaluate the learning outcomes and does not represent the user's identification accuracy.

$$R = N_{Identifications_{js}} / N_{Measurements} \quad (2)$$

$$I = (\omega_1 * N_{Identifications_{js1}} + \omega_2 * N_{Identifications_{js2}} + \omega_3 * N_{Identifications_{js3}} + \omega_4 * N_{Identifications_{js4}}) / N_{Measurements} \quad (3)$$

$$\omega_n = \frac{1}{p_n} / \sum_{n=1}^4 \frac{1}{p_n} \quad (4)$$

The accuracy indexes of participants based on the above formulas are shown in Figure 30. The accuracy index is 0 for number 3 participant, who ended the experiment early in the gamification condition because of discomfort with the VR device, and did not identify any joint set. Since the number of participants was small and an accuracy index of 0 interfered greatly with the results, the accuracy index data to participant number 3 was excluded. Figure 31 shows the calculated accuracy index in different conditions. The average accuracy index ( $N = 8$ ) in the gamified condition

Joint set	Point count	Color	Percentage	Difficulty weight
1	894380	Blue	0.7844	0.0106
2	164198	Green	0.1440	0.0575
3	11867	Red	0.0104	0.7965
4	69773	Yellow	0.0612	0.1354
Total	1140218			

Table 4: Joint set proportion from point cloud

was 0.0448 (median = 0.0348, SD = 0.0432), and the average correct rate in the non-gamified condition was 0.0211 (median = 0.0167, SD = 0.0149). Hence, it could be concluded that users had higher joint set identification outcomes in the gamified condition.

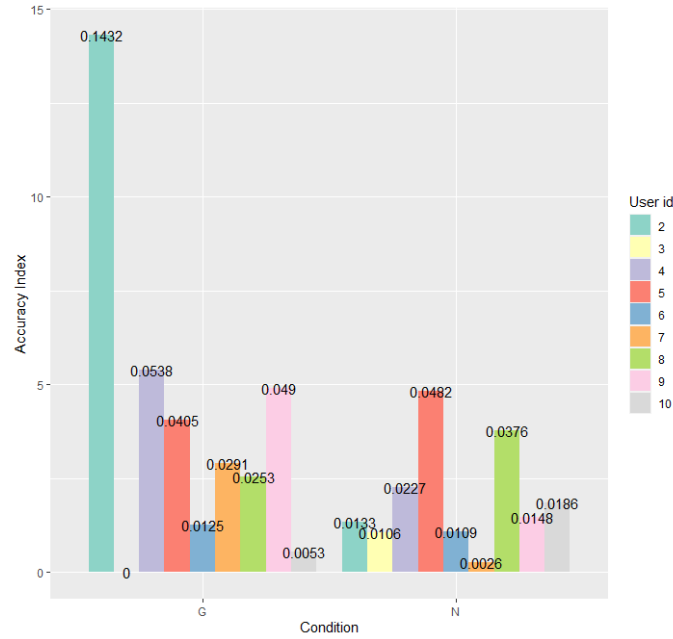


Figure 30: Accuracy index of participants

### Users prefer to use gamified content for learning

According to the participants' interview results (N=10), nine participants prefer to use the gamified content for learning and training, and one participant preferred to use the non-gamified content. The reason for gamification most frequently mentioned was the availability of instant feedback in the gamified content. The comments about instant feedback included *"you know you find something," "clearer if I had something," "(makes me feel) not alone in the environment."* The reason for the non-gamified content was because the participant wanted to learn in a calming environment. *"It's*

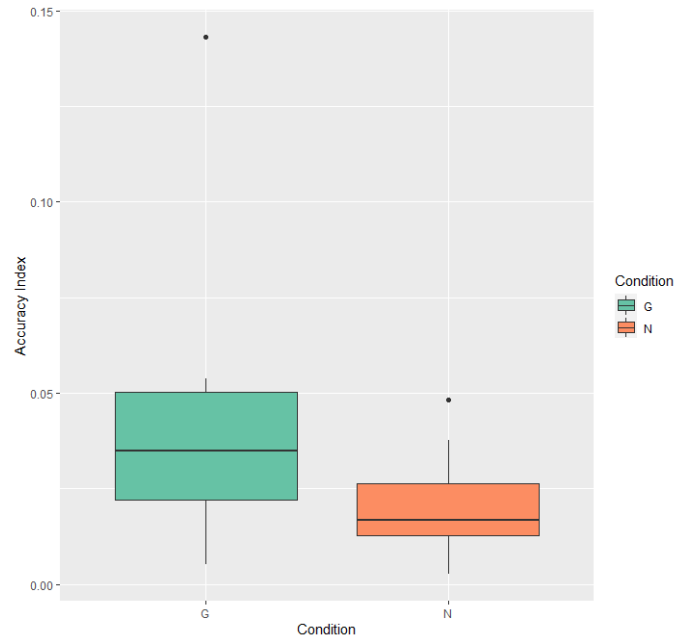


Figure 31: Accuracy index excluding number 3 participants

*calm and allow me to focus,*" said a participant who preferred non-gamified content. Table 5 below lists the reasons cited for the preference for the gamified content and the non-gamified content.

Reasons for gamified	Counts	Reasons for non-gamified	Counts
Instant feedback	9		
Fun	7		
Know if it was finished	4		
Well guided	2		
Immersive	2		
Allow mistakes	2		
Graphics	2		
Learned something	2		
		Calming	1

Table 5: Reasons for preference

The reasons mentioned for preferring the gamified content were also why participants perceived gamified content to be better than non-gamified content, and the impact of the gamification components. Specifically, participants perceived that the biggest disadvantage of the non-gamified content was that the results were not given immediately. The comments included *"don't know the result is killing," "don't know if I'm doing the right thing," "don't know what I'm doing"* and *"don't know when it*

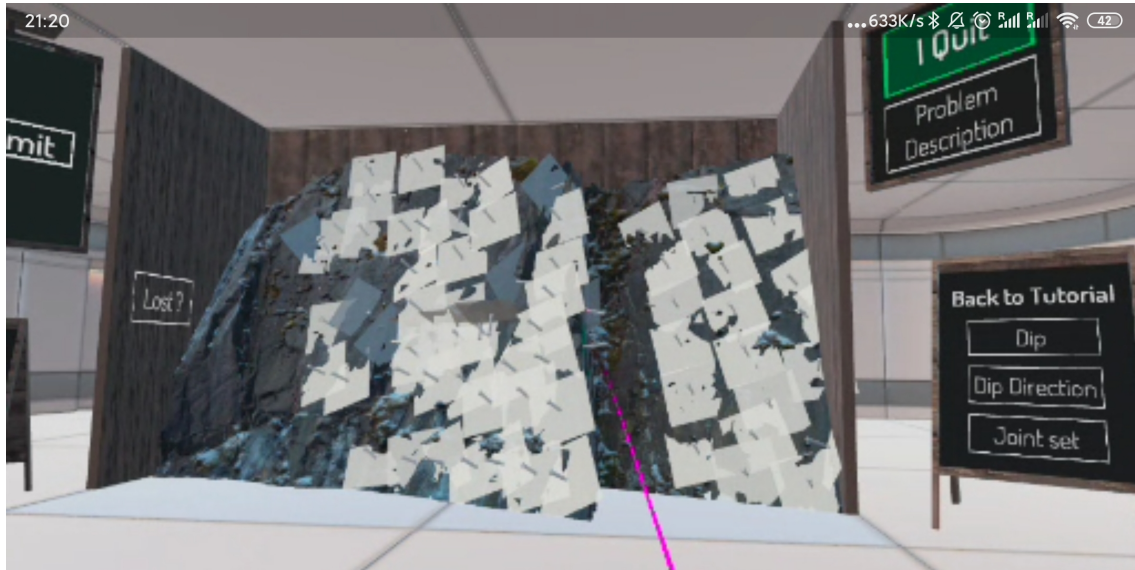
*will end.*" Secondly, participants mentioned that they felt lost in the non-gamified content and tried blindly without improving. Another participant mentioned that there was no background music in the non-gamified content made him feel *"scared,"* and it was *"too quiet like a hospital."*

### **Gamified content helps users learn the concepts**

One of the potential reasons for preferring the gamified system for learning was that participants believed that the gamified content helped them learn the concepts. As shown in Table 5, some of this help was the same as the reasons for the gamification systems preference. Besides, by answering the question, "Please explain the concepts a bit.", eight participants understood the content correctly, and two participants understood the joint set a little incorrectly. Six out of ten participants mentioned their willingness to learn the teaching content further. *"If it's in the same way (of GRETS) rather than textbooks,"* said one participant, *"I think I learned something when I measured,"* said another participant. After the experiment, three participants asked about the real-life application of the teaching materials, and one participant volunteered to try the GRETS again with the gamified exercise. Moreover, one participant with an undergraduate background related to rock engineering commented, *"This is much better than my old study experience,"* and asked if the demo video could be shared with her former research group.

At the same time, gamification showed behavior modification capability to help users learn. In detail, one participant (Participant number 8) first tried the non-gamified exercise, and her measurement behaviors are shown in Figure 32 (a). It was clear that the participant tried to measure every surface on the rock wall to achieve the exercise goal. The participant's measurement results are shown in the first row of Table 6 below. She took a total of 92 measurements, completed the task, and found all the joint set, with an accuracy index of 0.0376, which is above the average of the non-gamified exercise. However, observation and interview revealed that this participant failed to understand the concepts involved and made blind attempts to reach the goal. The participant said *"I don't know what I'm doing,"* when assessing her feelings about the non-gamified content.

This participant then tried the gamified exercise and skipping all teaching materials within 4.48 seconds. Without re-learning, she proceeded directly to the gamified exercise, and her measurement behaviors are shown in Figure 32 (b) below. Comparing the behavior in the non-gamified exercise, it is evident that this participant was not measuring blindly but rather purposefully attempting to measure according to



(a) Participant doing non-gamified exercise



(b) Participant doing gamified exercise

Figure 32: Screenshots from mobile monitor screen while participants testing the concepts. Her measurement data is shown in the second row of Table 6 below. Out of a total of 32 measurements, she identified three out of four joint sets. The accuracy index was 0.0253, which is lower than the results in the non-gamified exercise and the mean accuracy index in gamified exercise. Her understanding of the instructional concepts was also found to be inaccurate after the interview. However, she commented on the gamified content as "*(the gamified exercise) makes me feel like a different rock wall (from the non-gamified exercise).*"

Condi- tion	Measure- ment counts	Joint set 1 counts	Joint set 2 counts	Joint set 3 counts	Joint set 4 counts	Weighed accuracy index
N	92	54	4	3	2	0.0376
G	32	11	5	0	3	0.0253

Table 6: Measurement results of Participant number 8

Her measurement results indicated that in the non-game exercise, users could get the correct results and complete the objectives by blindly trying without understanding the teaching materials. On the contrary, in the gamified exercise, users could understand the teaching materials and completed the exercise correctly with the help of gamified components.

#### Users are motivated by gamification reward level

The components or reasons for gamification that motivate participant learning were varied. The frequent motivations mentioned were the wrist band, goal, and feedback. The specific components and times mentioned are shown in Table 7.

Component / reason	Wrist band	Goal	Feedback	Learn something	Researcher	Badges
Counts	5	4	3	3	2	1

Table 7: Motivations participants mentioned

Unlike previous expectations, badges were usually considered a common gamification reward, but they did not play a strong motivational role in GRETS. In fact, most participants mentioned that badges made the exercise more enjoyable but not motivational. Most participants stopped and laughed softly when they found the first badge, which represented that they noticed the badges and expressed positive emotions. *"Badges are a nice surprise,"* said one participant, *"badges make me happy and willing to try more,"* said another participant. *"it (badge) encourages me to do more,"* said the only participant who considered badges as her motivator. On the other hand, *"badges don't matter,"* said one participant, *"badges sometimes block my vision,"* said another participant.

The most motivational components mentioned by the participants were the wrist band (the progress bar) and the goal. The participants mentioned that the progress bar and the goal were to understand the process and conditions for completing the exercise.



These two components mentioned together were inferred as the reward level because the progress bar and goal were set to serve the exercise level. The participants also mentioned that they continued to complete the exercise. Similarly, five participants mentioned that GRETS needs more levels with various difficulties. Two participants directly mentioned *"need more levels,"* and three participants mentioned GRETS is *"too short," "too simple,"* and *"need to be more challenging."*

Participants mentioned other motivational components besides the wrist band and goals. For example, feedback reflected the consequence of their behaviors and let them know the current behaviors' rightness or wrongness. The reason "researcher" in Table 7 represented that the participants felt motivated because they were willing to help the researcher (the author) complete the experiment or felt the pressure for being observed. The reason "learning something" was surprising and unexpected because it represented that the participants had intrinsic motivation for learning the teaching materials, which was very precious. One participant described his motivation as *"curiosity of the possible combination of VR and concepts,"* and the other two participants described it as *"want to learn more about the concepts."* One possible explanation for the generated intrinsic motivation was that the concepts were considered to be complicated, and the learning time was relatively long and boring. During the learning process, participants' expectations for the actual application concepts in the gamified exercise increased. Compared with learning content, gamified content was more intuitive, interactive, and interesting. Participants became more excited and generated intrinsic motivation when facing gamified exercise. More inferences require extra experiments and data analysis.

### **Users are more excited in gamified content**

Through a user test method of think aloud and observation during the course of the experiment, participants expressed various emotions in the gamified exercise. In detail, most participants became more talkative in the gamified exercise, including exclamation, laughter, and *"hmmm"* sounds when thinking. Some of the participants even showed talking to themselves, such as *"Ok...it's the same joint set..."*, *"why it's not..."* These behaviors were consistent with the results of the interviews that GRETS was considered to be interesting and immersive. On the contrary, in the non-gamified exercise and the teaching content before the exercise, the participants were mostly quiet, and only expressed negative emotions like sighs when reading, and there was no talkative or dialogue with themselves. One participant even used "exam" to describe the experience in the non-gamified exercise. It indicated that participants

were relatively more excited in the gamified exercise than the non-gamified exercise.

### Users feel higher autonomy, competence and relatedness in gamified content

As in the first round of user testing, the UPEQ questionnaire results (N=10) were compared for two conditions. The detailed results are shown in Figure 33 and Table 8 below. It could be found that the scores of the gamified content in each subscale were higher than those of the non-gamified content. It also verified the previous conclusion: users are more willing to the gamified content.

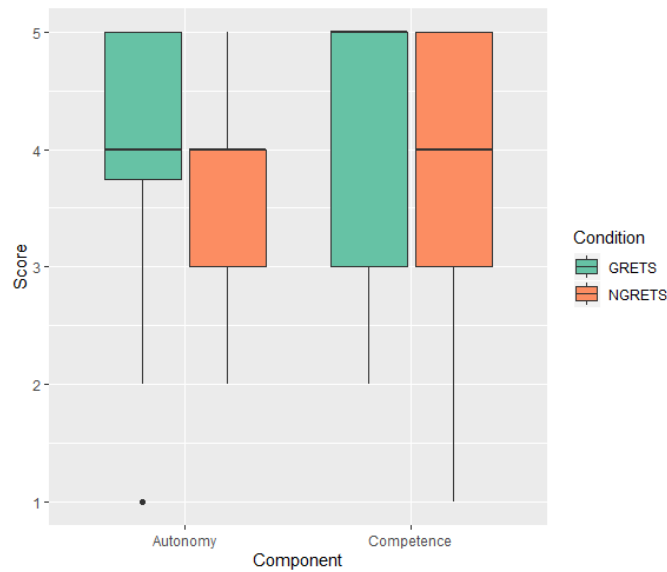


Figure 33: Second round user study UPEQ component results

	Mean	Median	SD
<b>Autonomy(G)</b>	4.066667	4	0.971922
<b>Competence(G)</b>	4.1	5	1.203103
<b>Autonomy(N)</b>	3.666667	4	0.968428
<b>Competence(N)</b>	3.8	4	1.286172

Table 8: Second round user study UPEQ questionnaire component scores

In GRETS, based on the questionnaires and SDT theory results, participants had high autonomy and believed that they could freely choose and control the game process. The free choice here refers to that participants can independently determine the measurement points, measurement speed, and playtime. For example, some participants mentioned, *"I can control my learning process"* in the interview. However, some participants also mentioned that there was not enough choice in the teaching

content, and they had to follow the established learning procedure. Participants also felt competence in the gamified exercise, they believed that their behavior was important, and their skills improved over time. A participant commented that he *"can find all (joint set) and learn something as long as spending time on it."* In the gamified exercise, it was found through observation that most participants became more purposeful in measuring behaviors, which is from random attempts at the beginning to purposeful measuring towards the end. This also indicated that participants' behaviors could be modified in the gamified content, and they could understand and master the teaching content in the process of using GRETS.

Although relatedness was excluded, to understand the need for relatedness, the participants were asked in the interview, "do you want to play together with others like a multiplayer game? If yes, collaboration or competition?" Three out of ten participants preferred to continue to use the single-player exercise because the current teaching content could be completed independently, and the behaviors of other players might interfere with their own learning effects. One participant who favored single-player commented, *"If multiplayer, different users have different learning progress. It might happen after the game, one is super good at it, and the other did not learn, but still have a high grade."* The remaining seven participants hoped that they could play with other people. Among them, four participants hoped to play multiplayer exercises in the form of cooperation, *"The goal is to learn the concepts rather than learn faster,"* one participant said. *"Competition is stressful," "losing is not fun even it's just a stupid game," "shorten learning time," "not lonely"* were also reasons mentioned by participants. The rest three participants hoped to play competitive multiplayer exercises because winning could help them learn in a focused and fast way.

## 5.4 Problems of traditional teaching and feedback from educators

In addition to the user tests, four educators from the Department of Civil Engineering, School of Engineering, Aalto University, who teach relevant rock structural mapping concepts, were interviewed via email about how their students performed in a traditional teaching scenario. The following questions related to traditional teaching were asked in the email.

- Did students have difficulty learning these three concepts (Dip, dip direction and joint set)? If so, what were the most significant or frequently mentioned

difficulties?

- How much time is spent on teaching those concepts (both in the classroom and in the field)
- How long does it usually take for students to understand these three concepts?

Besides the interview questions, the demo video in Appendix A.3.1 was also shared, and educators were asked to share their opinions about GRETS if they were interested. Their answers could measure whether GRETS could improve traditional teaching methods' shortcomings and their opinions on using GRETS in a real teaching scenario from a professional perspective.

#### 5.4.1 Results

##### **There are problems in traditional teaching**

According to the educators' answers, the teaching concepts involved in GRETS are not taught for a long duration in the actual teaching. *"There is not much time to spend on teaching the concepts (a half an hour max)"* said Professor Jussi Leveinen, who is responsible for the engineering geology course at Aalto University. *"Most of the students can understand the concepts rather fast, but few have problems with understanding the 3D nature of the concepts."*, said Lecturer Juha Antikainen, who is in charge of the exercises of Rock Mechanics course at Aalto University. However, after the concepts are understood, the students have difficulty applying correct concepts to practical exercises. *"... practical measurement is a bit step further, that involves difficulties."* said Professor Mikael Rinne, who is in charge of the Rock Mechanics course at Aalto University. Moreover, *"Some students also find the manual measurements and the use of non-digital compass very difficult and confusing. That means that one must spare some time for repetition,"* said Professor Jussi Leveinen. At the same time, students may not remember the concept for the long-term. *"After the lecture I guess they somewhat understand these concepts, but cannot really apply them. Most likely they will not remember the concept after one year from the exam, if there is no practical training."* said Professor Mikael Rinne. In summary, in the current actual teaching, students have no problem understanding the concepts, but it may be more helpful if there is an explanation from a 3D perspective. Besides, there is a certain gap in the learning process from concept to the actual measurement, and repetitive practice exercises might help students build long-term memory about the concepts.

### **Educators hold positive opinions about applying virtual reality and gamification in rock engineering education**

Furthermore, the demonstration video of GRETS was also sent to four educators who had previously been interviewed. *"I think that this virtual reality training is excellent and helpful in many ways,"* said Professor Jussi Leveinen. *"The long-term learning is difficult to evaluate, I'm afraid that many students forget the content quite soon. I believe the 3D virtual mapping will help with this,"* said Lecturer Juha Antikainen. After completing this thesis, GRETS will be applied in the two courses GEO-E1010 – Engineering Geology (5 ECTS) and GEO-E2030 – Rock Mechanics (5 ECTS) at Aalto University for more research in recent future.

## 6 Discussion

GRETS is a gamification application for the teaching and practicing rock characterization and structural mapping concepts, including concept teaching and a practical training with a photorealistic rock wall. Three concepts (dip, dip direction and joint set) 3D teaching content, remote measuring method, interactions with the rock wall, and a gamified exercise, were designed and implemented in GRETS.

By analyzing the results of the two rounds of user study, research questions can be answered. Gamified exercise is a conceptual practical training that helps users shape their behaviors to properly understand and master the instructional content, as discussed in many studies such as [36], [3], [1], [53]. Regarding the two badge designs of gamification, users preferred the traditional badge because the collection process of the physical badge interrupted the measuring behavior. Moreover, in GRETS, the users' instructional results were consistent with the real learning environment. For example, users spent the longest time learning the concept joint set among the three concepts and spent more time practicing the concept to learn it than reading-based learning. Users' measurements in the GRETS exercise were also consistent with real rock body data and expert expectations.

Although unfamiliarity with VR devices caused some difficulties, users enjoyed learning through GRETS. Compared to the non-gamified exercise, 90% of participants preferred to use the gamified exercise for more interesting, entertaining practice. 10% of the participants preferred to use the non-gamified exercise for calm reflection and learning. Most participants were in a relatively exciting emotional state when interacting with the gamified content, consistent with results in [54] and [55]. The gamified exercise elements that users liked the most were instant feedback and goals because they allowed users to understand the "rightness" or "wrongness" of their actions and win the exercise, as discussed in [55], [5]. Additionally, users perceived that their motivation when playing a gamified exercise came from the gamification reward level rather than from the badges as previously assumed. According to the SDT theory and the UPEQ questionnaire results, users' intrinsic needs (autonomy and competence ) were more satisfied in GRETS than in NGRETS. Relatedness was excluded because GRETS is a single-player system that users do not have strong social connections with other people. At the end of the experiment, 60% of participants reported they would continue learning the teaching content. In other words, their intrinsic motivation toward the teaching content was increased, consistent with results from [56].

Besides better user experience, gamification also increased the amount of time users spent on the exercise and their measurement accuracy rate. In detail, by applying the gamification method, the percentage of time spent in exercise increased from 25.6% to 34.25% of the overall usage time, and the accuracy index of users' joint set identification rose from 2.59% to 5.53%. This thesis attempted to identify the relationship between the accuracy index and other factors, such as concept learning time and exercise duration time, to find a direct way to improve the accuracy index. Figures 34 (a), 34 (b) are the line graphs corresponding to concept learning duration and the accuracy index, exercise duration, and the accuracy index. However, because the data set was too small, finding the statistical relationship between the variables was impossible.

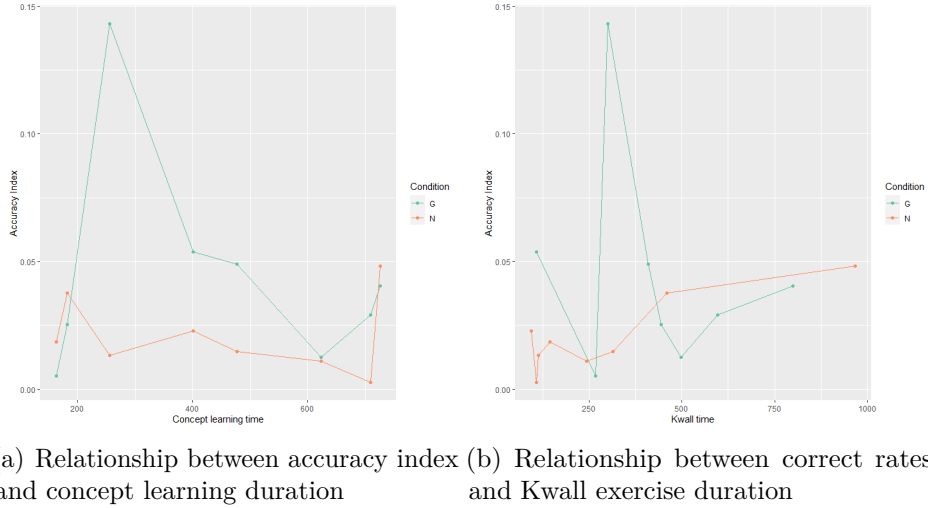


Figure 34: Kwall time duration differences between conditions

## 6.1 Limitations

However, there were still some validity issues in conducted user studies. First of all, the external validity issue is that the user study participants were not the target user groups of GRETS. In real-world testing situations, users, for example, master students in rock engineering, were hard to access because of the 2020 COVID-19 pandemic. As the World Health Organization (WHO) suggested, school and work were transferred into remote-mode for safety reasons [52]. Although the situation improved when conducting user tests, universities were still remote as advised, and people were working from home, which caused difficult access to users. Besides, a VR headset is one potentially contaminated object, especially when wearing one. Oculus Quest, which is used in this thesis, touches the user's face, nose, and eye area



directly with its headset, as shown in Figure 22, and two hand controllers need to be held. Hence, to keep users safe, they were asked about their health state and sterilized their hands before tests. After tests, each headset was in no-use for at least 3 hours, and VR devices were wiped with disinfection wipes. Besides, high-density user tests were avoided by separating all schedules so that users did not need to contact a large group of people. These objective factors slowed down user testing and limited the number of users that could be accessed.

Second, the low number of participants prevented establishing the statistical significance of the results. Thus, all quantitative results remain inconclusive. Unfortunately, to complete the GRETS evaluation on time, this was a compromise that had to be made due to the insufficient number of researchers, time constraints, and the fact that it was difficult to reach participants. However, the author still reported the results to provide a possible gamification design in rock engineering education and hope to have something other researchers could build on.

As for the interaction design in GRETS, the remote measuring method also had some shortcomings. It needs to be noted that the measurement data acquired by the remote measure method in GRETS was based on a point rather than a rock mass surface. In other words, the data calculated by the remote measuring is not 100% accurate, especially at outcrops, depressions, and surface edges in a rock mass. This remote measuring feature made the measurement data highly influenced by the resolution of the model and measurement locations, especially for small, horizontal surfaces. In practice, it was easy for the users to fail to identify the joint set because of edges or bumps when measuring the red joint set (see Figure 10 (b)). A possible improvement would be to capture a radius of points around the aiming point, then map those points to the best-fitting plane and use that plane information for the calculation. Another fact was that, as mentioned in the System design chapter, the ranges of joint sets used in GRETS were narrowed down to achieve similar measurement results in VR as in real scenarios. In the absence of an existing corresponding standard, joint set data in GRETS was narrowed down based on one expert's evaluation. However, in user tests, there were some identification errors because of the narrowed ranges. Some measurements that should have been identified to a joint set were mistakenly classified as not belonging to any joint set, which led to confusion and additional attempts by some participants.

Last but not least, due to time and technology limitations, there are still some flaws in the game design of GRETS. For example, the teaching content has not been

gamified, and the design of game elements was not perfect. The second round of user study results proved that the gamified rewards assumed did not motivate users to learn. On the contrary, the reward level recognized by users as a motivator in user tests was not focused on design, which might affect the evaluation result of the influence of gamification. On the other hand, one reason why badges were not considered as a motivator might be because of the shortage of gamification design. In detail, each user test conducted took about 90 minutes, including experiment settings and interviews, and it was hard to extend the duration. Otherwise, participants might be tired, and the evaluation might be biased. However, participants only spent 426.98 seconds (around 7.12 min) in the gamified exercise. In real scenarios, learners are expected to spend more time on the system without disturbance, such as interviews. In order to explore the role of the badge in such a short duration, the badges in GRETS were designed to be easier to achieve. Participants received an average of 5 badges out of 10 (median = 5, sd = 0.93) in the gamified Kwall exercise. As shown in Figure 35, participants were rewarded with similar badges. Moreover, badges, which related to exploring, such as "Jointset\_TooMuch" and "Fire" (see Table 2), were not achieved even once. One possible reason was that the content of gamification is limited, and participants had a clear mission. In other words, they could not carry out enough exploratory behaviors in such a short time. However, if users have enough time to explore or repeatedly use GRETS for learning, they might have different feelings for badges.

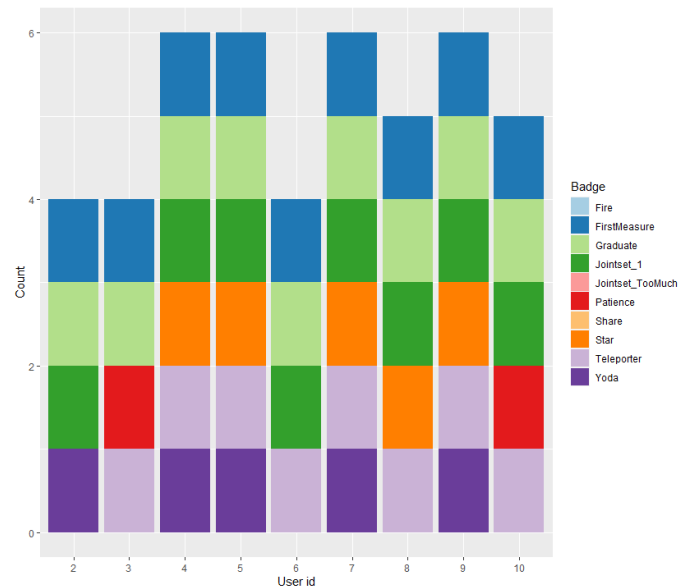


Figure 35: Badges rewarded in GRETS during user tests

## 6.2 Future work

Compared with the previous VR teaching system VUTE [9], the entire user experience has been improved by applying gamification. Besides, GRETS adds the ability to measure remotely, record learner interactions, and remote result collection, which reduces teachers' difficulties in collecting results and evaluation. The design and implementation of gamification applications can help learners learn the teaching content and improve their learning experience, intrinsic motivation, and other learning outcomes. The application of gamification is a possible way to improve user experience and learning outcomes. In subsequent research, it is hoped to involve more users and conduct user studies to further evaluate the impact of gamification on rock engineering education.

Specifically, there are four recommendations for the future system. First, use animation or video to replace the current text teaching in GRETS. This may narrow the gap between reading and understanding, making it easier and more accurate for learners to learn the teaching materials. Another option is to prepare a short lecture or notes in real-life before using GRETS and only do gamified exercises in VR, which might be easier to implement than creating animations. Second, make the instructional content into a level model to further increase the flexibility of teaching content and articulate the various instructional objectives in levels unlock. Multiple different rock practice scenario levels are also expected to be designed and implemented. This would also apply the gamification method to teaching sessions, not merely to exercises, and can further enhance learners' motivation through the gamification reward level. The level unlocking approach can provide better guides and intuitive relationships between various teaching objectives. For instance, learners can proceed to the joint set learning level only after completing dip and dip direction levels. According to the user study results, such initiatives can increase user autonomy and competence, increasing the intrinsic motivation for teaching content. Future research can refer to the level design under the goal-setting theory [57] and design challenging levels that do not exceed the learner's ability to stimulate learners' learning motivation. Third, pay attention to the design of VR content. The results of the current user study showed that some participants experienced discomfort while using VR devices. In subsequent studies, the VR content design could be optimized, such as first instructing users to adjust the device for proper wear at the beginning of the system. Users can also be reminded by researchers to wear the devices properly before the experiment. Fourth, optimization for gamification design. For example, adjust the badge settings to explore whether

badges can motivate learners and add more special effects to make the environment more immersive. Furthermore, a character could be added to act as a tutor for the whole system to satisfy the relatedness needs of users.

## 7 Conclusion

This thesis conceptualizes a teaching system for teaching rock structural mapping, GRETS, applying virtual reality and gamification, and a mixed-method study to measure the influence of gamification techniques. According to the results, GRETS helps learners learn three rock structural mapping concepts - dip, dip direction, joint set - and practice in a practical gamified exercise. GRETS fills the blank of lacking gamification applications in rock structural mapping education and improves the learning experience and outcomes.

In GRETS, gamification is focused on the exercise session. Nine game elements were designed and implemented, including the clear goal, messages, graphics, the wrist band, sounds, visual effects, haptic, badges, and the scoreboard. A new attempt was made to design a game element badge - the physical badge, and a within-subject study (N=4) was conducted to compare the performance with the traditional badge. The results showed that although the physical badge was better at attracting users' attention in a virtual environment, it interrupted the primary exercise process and decreased the user experience. Therefore, the traditional badge was used in GRETS for a stable user experience. The second within-subject user study (N=10) was to measure the influence of gamification on the learning experience and outcomes. An instructional system, NGRETS (Non-Gamified Rock Engineering Teaching System), was developed with the same content without gamification techniques. The results showed that the gamified educational system provided better user experience and learning outcomes than the non-gamified system. Additionally, users perceived that users' most motivational game elements are feedback and goals rather than badges. The behaviors and outcomes that users performed in the virtual exercise were consistent with the real-life learning scenarios. Besides, the intrinsic needs (autonomy and competence) of users were satisfied through gamified content. In summary, the application of gamification can change user behaviors for educational purposes and improve user experience and learning outcomes. It needs to emphasize that due to various limitations, the low sample size prevents reliable statistical analysis.

This research contributes to the field of rock engineering education and the application of gamification. It fills the gap of gamification application in the field of rock engineering teaching, especially for master students, and compares the user experience and learning outcomes of gamified and non-gamified teaching systems by quantitative and qualitative methods. Despite the limitations, GRETS is hoped to be a valuable exploration for future gamification applications and provides possible self-learning

and training applications for rock engineering education. The thesis advances the gamification of rock engineering education and provides a novel example case that other gamification researchers, designers, and educators can build on.

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## A Appendix

### A.1 UPEQ questionnaire

1. What is your gender? \*

Mark only one oval.

☐ Female

☐ Male☐ Prefer not to say

2. What it your age?

How do you agree with the following statements?

1 - strongly disagree, 2 - disagree, 3 - not sure, 4 - agree, 5 - strongly agree

3. I was free to decide how I wanted to [play]. \*

Mark only one oval.

1            2            3            4            5

Strongly disagree ☐ ☐ ☐ ☐ ☐ Strongly agree

4. I could approach [the game] in my own way. \*

Mark only one oval.

1            2            3            4            5

Strongly disagree ☐ ☐ ☐ ☐ ☐ Strongly agree

5. The game allowed me to [play] the way I wanted to. \*

*Mark only one oval.*

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

6. I had important decisions to make when [playing]. \*

*Mark only one oval.*

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

7. The choices I made while [playing] influenced what happened. \*

*Mark only one oval.*

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

8. My actions had an impact on the [game]. \*

*Mark only one oval.*

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

9. With time, I became better at [playing]. \*

*Mark only one oval.*

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

10. My [gaming] abilities have improved since the beginning. \*

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

11. My mastery of the [game] improved with practice. \*

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

12. I was good at [playing]. \*

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

13. I felt competent at [playing]. \*

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

14. I felt very capable and effective when [playing]. \*

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

15. What other players did in the game had on impact on my actions. \*

*Mark only one oval.*

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

16. I had to adapt my actions to other players' actions. \*

*Mark only one oval.*

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

17. I felt close to some of the characters. \*

*Mark only one oval.*

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree

18. I cared about what happens to some of the characters. \*

*Mark only one oval.*

	1	2	3	4	5	
Strongly disagree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strongly agree



## **A.2 Interview questions**

### **A.2.1 The first round of user study for badge types**

1. Did you ever play VR games?
2. Did you know or heard about dip / dip direction / joint set?
3. Do you think you understand the concepts now?
4. How do you feel after playing?
5. Which game impressed you the most ? and why ?
6. Do you like the physical badge?
7. Did you play some similar physical badges before?
8. Do you want to play a game with physical badges or normal badges?
9. Are you interested in learning these concepts more if possible?
10. Do you think it counts for a “game”?
11. Do you want to play together with others? If so, collaboration or competition?

### **A.2.2 The second round of user study for gamification**

1. Did you ever play VR games?
2. Did you know or heard about dip / dip direction / joint set?
3. Do you think you understand the concepts now? Please explain a bit.
4. Are you interested in learning these concepts more if possible?
5. Did you enjoy the learning experience?
6. How do you feel after playing?
7. Which system impressed you the most ? and why ?
8. Do you like the gamified content? And why?
9. Do you think it’s fun?
10. What motivates you to continue learning? (for each game)
11. Which system do you prefer to use?
12. Do you think the gamified system helps you to learn?

13. Do you think the gamified system counts for a game?
14. Do you want to play together with others like a multiplayer game?
15. If yes, collaboration or competition?
16. If users did not notice about the badges: Do you have any clue why you did not notice the badges? Then what makes you continue learning?

## **A.3 Demo videos and published website**

### **A.3.1 Demo videos**

- This video illustrates the core feature of GRETS: [The 2-min feature video](#)
- This video illustrates the second round of user study to measure the impact of gamification: [GRETS VS NGRETS demo video](#)

### **A.3.2 Published website**

GRETS has been published as COVE (Conceptual orienteering in virtual education) project on Aalto Online Learning website: [COVE project](#)